MASTER

Optimizing the long lead time supply chain of Office Depot Europe

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Award date:
2018

Master Thesis

Optimizing the long lead time supply chain of Office Depot Europe
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In partial fulfilment of the requirements for the degree of
Master of Science
In Operations Management and Logistics

Office Depot Europe

Date: March 30, 2018

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Series Master Theses Operations Management and Logistics

Keywords: Supply Chain Management, Inventory management, Proactive Emergency Shipments, proactive Lateral Shipments, two-echelon, Review period.

Abstract

This master thesis document presents the development of a model to calculate, analyze and compare the expected total costs of different supply chain setups for items imported from China by Office Depot Europe. The model consists of; the expected transportation costs, including the number of containers and trucks; inventory holding costs, including storage space used and interest; and inbound and outbound costs, including labor and usage of forklifts and package materials. The correctness of the model has been checked by comparing the expected costs from the model with the actual costs. The model evaluates several supply chain setups in order to give a recommendation on the preferred supply chain setup. First the impact of using a central distribution center is checked, secondly the impact of using lateral shipments, thirdly the impact of emergency shipments and finally the impact of changing the review period. Furthermore, a new safety stock calculation, taking these setup choices into account is introduced. The model showed a preferred setup with a central distribution center for roughly 20% of the items.

Preface

This report is the result of my graduation project at the supply chain and optimization team of Office Depot Europe in Venlo. This master thesis is the final requirement to obtain my Master of Science degree in Operations Management and Logistics at Eindhoven University of Technology. During this project I have learned many new things and made several personal and professional developments. Towards the end of this project I am starting to realize that this is the final part of my life as a student and the start of being part of the working community. However I am convinced that this is not the end of my learning life, since I will always keep learning. I would like to thank a number of people for their support during my master thesis project and the rest of my study.

First of all, I would like to thank Bart op 't Veld for giving me the opportunity to do my project at Office Depot, you were a great supervisor and have a lot of knowledge on various topics. We had several great meetings and discussions during the project, which really helped me keep going forward in the right direction. Additionally I would like to thank Harald Vullings for assisting me through the first phase of my project and helping me out in getting to know the company and the import process from China. Furthermore, I would like to thank my colleagues at Office Depot, with in particular my colleagues in the Own Brand, Transportation and Supply Chain Optimization teams, who provided me with business insights and information. Finally I would like to thank Luuk van Bergen for being my neighbor during this project, providing me with some great laughs and more important, coffee every once in a while.

I would also like express my gratitude towards Shaunak Dabadghao, my first supervisor at the TU/e and my mentor during my master. Thank you for your feedback and support, you were of great help to me and kept me focused on my end goal during my master and thesis. Especially your insights on the overall process helped me to keep going in the right direction. Furthermore, I would like to thank Zümbül Atan, my second supervisor at the TU/e. Thank you for your honest comments on my documents and for reminding me to make a clear overview of all calculations and assumptions. This was of great help to me and brought my project to a higher level. Finally, I would like to thank my fellow students for the great time, projects and discussions during my master and pre-master. In particular, I would like to thank Luc Sonneville for the great morning coffees at Julias.

Last but definitely not least I would like to thank my family with in particular my girlfriend Kirstin and my parents Engelbert and Rionne. Kirstin, thank you for your amazing support, patience and critical notes, I wouldn’t be where I am right now without you. Mom and dad, thank you for your support during my master and bachelor and for being always there with a nice cup of coffee.

Filip Obers

March 30, 2018

Management summary

In long lead time supply chains with multiple final warehouses many different supply chain setups can be chosen. In this research the supply chain setup of Office Depot Europe has been evaluated. In this evaluation the usage of a central distribution center, lateral shipments and emergency shipments have been taken into account. The project started with a management dilemma. Based on which a main research question has been developed. The management dilemma and main research question were:

Management dilemma: *The supply chain cost and on hand inventory value of the private label products sourced in Asia is too high.*

Main research question: *How should the supply chain of products sourced in Asia be setup in order to minimize supply chain cost and on hand inventory value while maintaining the current product availability level?*

The supply chain costs consist of several relevant factors. Costs are considered relevant when they can be influenced within the scope of this research. Some relevant costs are transportation and storage costs. Possible cost savings can be achieved by switching between a direct or indirect flow, i.e. shipping directly to the LDC's or indirectly via the CDC. This will lead to different storage and transport costs due to for example order minima's. An additional possibility would be to use emergency and lateral shipments to reduce inventory while maintaining current product availability levels. However, this would cause additional transportation costs. To gain some insight the average stock turn of the first months of 2017 has been calculated. Office Depot has a target stock turn of 12. The actual average stock turn however was 7, for only own brand items the average stock turn was below 4. Office Depot is aware that longer lead times yield lower stock turns but still thinks an improvement is possible.

In order to answer the main research question the actual and preferred supply chain setup of Office Depot were required. These were determined in several steps.

1. The actual setup and performance is determined by gathering data and calculating the total costs of all different relevant cost factors. These cost factors were: transportation costs, inventory holding costs, inventory handling costs.
2. The preferred setup is determined by comparing the total expected supply chain costs. In order to calculate these costs a model has been developed. The correctness of this model has been tested by comparing the model output based on the current setup with the actual performance.

The model that calculates the expected costs has been developed based on literature. The research of Wijnberg (2015) was used as starting point for the total cost calculations and the research of Suavita (2012) was used as starting point for the safety stock and reorder levels. These calculations have been updated based on:

- Swenseth & Godfrey (2002) who assume transportation costs only dependent on shipment size
- Naseraldin and Herer (2011, p. 444) who described a calculation for the total expected costs including lateral transshipments
- Lau et al. (2016) who described a method to select a preferred supplier
- Alfredsson & Verrijdt (1999) who describe a reactive system with lateral and emergency deliveries
- Tagaras & Vlachos (2002) who described a method for lateral shipments with additional safety stock levels which is used to take emergency shipments into account.

The developed total cost function was used to calculate the expected supply chain costs based on the supply chain setup. By iteratively checking the expected costs of different setups, a preferred setup was chosen. This was done by first calibrating the calculations (comparing model and actual

performance based on current setup), this resulted in a baseline. The baseline is compared with the expected performance of other setups. The best performing setup was selected as preferred setup.

The preferred setups for the individual options (CDC usage, lateral shipments and emergency shipments) have been determined via specific algorithms. These algorithms started by using the CDC flow, lateral shipments or emergency shipments for all items and warehouses and determined the expected costs of this setup. Then for each item and warehouse the costs when not using the CDC flow, lateral shipments or emergency shipments were calculated. The “switch” with the lowest expected total costs is selected. This is repeated until no item and warehouse uses the CDC flow, lateral shipments or emergency shipments. The costs of each iteration were stored and the setup with the lowest costs is selected as preferred setup.

The preferred supply chain setup determined via the above analysis gave several possible changes in the supply chain setup. Some other parts however should remain. Therefore, the different parts of the supply chain setup that should and should not be changed are discussed below.

- The number of echelons should remain at 2 for a select number of items. Compared to the current setup the % of items following a direct flow should be reduced from 26 to 20%. At this moment, most savings (up to 10%) can be made by reevaluating for each item whether it should follow a direct or indirect flow since the model indicated that 20% of the items should switch from direct to indirect or vice versa.
- In the long term, it should be considered to relocate the Central Distribution Center to China, however some additional information should be gathered before making this decision (see future research). Additionally the impact on the items of European vendors that are ordered via the CDC should be taken into account since these need to be switched to direct delivery.
- The current transportation method, sea freight, should be maintained. Using emergency or lateral shipments for a fixed percentage of demand is not interesting, however when extremely unexpected demand occurs they could be used to cover the gap (accepting higher costs).
- The current safety stock calculations should be reevaluated, especially for the Central Distribution Center since at this moment there is no calculation behind the safety stock value. This could give up to 15% inventory value reduction. Office Depot could also choose to improve the service level of the Central Distribution Center, which would theoretically yield lower safety stock at the Local Distribution Centers and possibly making the usage of the CDC interesting for more warehouses.
- Changing the review period is not recommended since this would increase the total costs. Switching to a two week review period does reduce inventory value and expenses, however the transportation costs increase more. Switching to a six week review period does reduce the transportation costs, however the inventory expenses increase more.
- The reorder level calculations are fine, as long as the safety stock calculations are improved.
- The current forecast method has not been evaluated extensively since the forecasting method was too vague to give good comments on. Additionally Office Depot is evaluating this performance internally. When the forecast performance is improved this should be taken into account in the safety stock calculations since a better forecasting performance yields a lower safety stock.

Limitations: This research has some limitation due to assumptions and time constraints these are discussed below:

1. The in transit costs were excluded due to vendor agreements, however when switching to a CDC in China these costs would become relevant. It could be argued that these costs are somehow included in the item price at this moment. Therefore, the item price or minima’s agreed with the vendor could be reduced when delivery in China is requested instead of EU delivery.

2. No data available on the handling and storage costs of a CDC in China, therefore some assumptions were made for these handling and storage costs.
3. Transportation costs are calculated based on the expected number of pallets per container and truck. Corrections were made for the fill rate of a container and the stacking of pallets in trucks, however this is not an exact approach.
4. Some items and warehouses were out of scope, therefore not all costs have been taken into account. Taking these items into account would change the total costs. However, it is expected that the overall conclusion remains the same.

Recommendations: Based on the analysis performed during this project several possible improvements came forward. Therefore several recommendations for Office Depot to improve their overall performance are:

1. The CDC forecast is made per warehouse, however a major strength of a CDC is variability pooling which is obtained by making a forecast on the total demand instead of the individual demands.
2. The safety stock in the CDC should be based on demand variation instead of a fixed number of days selected based on trial and error without taking variance into account.
3. The decision to select either a direct or indirect flow should be made while taking the overall costs into account, i.e. instead of evaluating whether a local warehouse has sufficient demand to send directly it should also be evaluated whether the other warehouses can miss the demand of that warehouse in their central order.
4. The vendor agreements should be evaluated since for some items the minima's agreed with the vendors are bigger than one year of demand. Causing unnecessary high inventory. If the vendor constraints would be completely removed a cost reduction of up to 8% could be achieved, regardless the selected setup. In addition to this vendor lead times should be included in the contracts since right now the vendors give an estimate of the lead time at the moment the order is placed based on which there performance is measured. This gives the suppliers the opportunity to change its lead time each order.
5. In planning the actual vendor lead time should be used instead of the (at this moment non-contractual) agreed lead time since otherwise orders might be placed too late or early due to changes in the actual lead time causing over- or understocking.

Future research: During this project several possibilities for future research were discovered. These will be discussed below:

1. This project had a wide scope to check and improve the current overall supply chain setup. Therefore, it was not possible to gather all information on a CDC in China. In future research the cost differences between a CDC in China and Europe should be evaluated making the decision more clear. Additionally it should be evaluated whether the possible storage space that is saved in Europe for not using the CDC can be used (opportunity costs).
2. In this project the service levels of the CDC and LDC's remains fixed. However, in future research the optimal CDC service level could be evaluated that minimizes the total supply chain costs with the required service level in the LDC.
3. Using palletized containers instead of loos loaded containers. This will yield fewer items per container but it will lower the inbound costs at the local warehouses since unloading palletized containers is faster than unloading and palletizing loose loaded containers.
4. Introducing a periodic review on vendor selection. This should be introduced to ensure that a decision to select a certain vendor made x periods ago is still the best decision. In this review the vendor constraints should be discussed as well since, regardless the supply chain setup reducing the vendor minima's could yield up to 8% cost savings.

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Abbreviations

- α = The required overall service level
- α' = Updated service level for different review period at CDC and LDC
- δ_j = Percentage of demand satisfied from warehouse i
- μ_{ij} = Average weekly demand of item i at warehouse j
- σ_{ij}^2 = Demand variation of item i at warehouse j
- σ_{Lij}^2 = Lead time variance for ordering item i at the corresponding vendor with delivery to warehouse j
- σ_{LJj}^2 = Lead time variance for shipping from central warehouse J to warehouse j
- $baseR$ = Base review period (4 weeks)
- $containers_{pjx}$ = Number of containers shipped from port p to warehouse j of size x
- $containersE_j$ = Containers shipped to warehouse j
- eP = Emergency percentage
- $EuroPerPallet_j$ = Costs per year for storing 1 pallet
- i = Item number {1,…,I}
- $interest$ = Interest percentage
- I = Total number of items
- $\bar{I}_{ij}$ = Average inventory of item i at warehouse j
- IBC_j = Annual inbound costs at warehouse j
- $ItemFlow_{ij}$ = Flow of item i to warehouse j with 0 and 1 for direct and indirect delivery respectively
- j = Warehouse number {1,…,J}
- J = Total number of local warehouses + CDC
- $\hat{k}$ = Target service factor without allowed lateral shipments, with allowed emergency shipments
- k = Target service factor with the impact of the allowed lateral and emergency shipments
- $\widehat{kE}$ = Target service factor without the impact of the allowed emergency shipments, without impact of allowed emergency shipments
- kE = Target service factor with the impact of the allowed lateral shipments based on $\widehat{kE}$, without impact of allowed emergency shipments
- l_j = Lead time for warehouse j
- L_i = Lead time of item i
- lat_{ij} = True if lateral flow allowed for item i at warehouse j
- N = Number of warehouses
- OBC_j = Annual outbound costs at warehouse j
- P = Number of discharge ports
- $pallets_{pjx}$ = Pallets shipped per review period from port p to warehouse j in a container of size x
- $pallets_{pj}$ = Total number of pallets shipped per week from port p to warehouse j
- $PalUn_i$ = Items of type i per pallet
- $port_i$ = Port of discharge of item i
- PpC_x = Pallets per Container of size x
- $pref_{iwj}$ = True if warehouse w is the preferred supplier of item i to warehouse j.
- $Price_i$ = Purchase price of item i
- Q_{ij} = Order multiple for item i at warehouse j (note: is not the same Q as in previous chapter)

- R_{ij} = Review period of item i at warehouse j
- RT_j = Annual road transportation costs to warehouse j
- SC_j = Annual storage costs at warehouse j
- SCC = Annual Supply Chain Costs
- SF_j = Annual sea freight costs to warehouse j
- SS_{ij} = Safety stock of item i at warehouse j
- SSE_{ij} = Safety stock for emergency shipments of item i to warehouse j
- TC_j = Annual transportation costs to warehouse j
- TCC_{pjx} = Costs of shipping one container of size x from port p to warehouse j
- $TCCE_j$ = Transportation costs per container to warehouse j
- TCE_j = Annual transportation costs emergency shipment to warehouse j
- TCT_{wjy} = Cost of shipping y pallets from warehouse w to warehouse j
- $trucks_{wjy}$ = Number of trucks shipped from warehouse w to warehouse j with y pallets
- Var_{ij} = Variance component of item i at warehouse j
- X = Number of different container sizes
- Y = Number of different truck sizes, being the number of pallets fitting in a truck.

1 Introduction

In long lead time supply chains with multiple final warehouses many different supply chain setups can be chosen. In this research the supply chain setup of Office Depot Europe has been evaluated. In this evaluation the usage of a central distribution center, lateral shipments and emergency shipments have been considered. The preferred setup has been selected based on the total expected supply chain costs. However to calculate these costs the inventory value was required, which is influenced by the supply chain setups. Finally, in order to give recommendations on changing the supply chain setup, the current setup had to be known. To provide the reader some guidance in reading the report the chapters are briefly described below.

In chapter two an introduction to Office Depot is given to provide an overall understanding of the analyzed company and process. In chapter three the management dilemma and research questions are discussed followed by the project boundaries and research methodology to provide insights in the research problem and approach used to solve the management dilemma. In the fourth chapter a summary of the extended literature research has been given, discussing research on the use of central distribution centers, lateral shipments, emergency shipments and data distribution selection. Chapter five provides the current supply chain setup followed by the current supply chain performance in chapter six. These were used to calibrate the developed model. In chapter seven the model to calculate the expected total costs is explained followed by the methods to determine the preferred item flow, number of lateral shipments and number of emergency shipments. Based on these methods and calculations chapter eight shows the results of the different supply chain setups and concludes with giving the preferred supply chain setup. Finally chapter nine gives the overall results, conclusions, research limitations, recommendations and suggestions for future research.

2 Office Depot

This chapter introduces Office Depot, the company that developed the management question and dilemma and at which the thesis project has been executed. Office Depot is introduced via some company statistics and clarifications. Additionally the relevant sourcing process with the suppliers and warehouses for the own brand items imported from China is explained since that has been the focus of the thesis project.

2.1 Office Depot

Office Depot Europe is a reseller of stationary and furniture products of both OEM[1] and private label brands with a turn-over of €1.5 billion in 2016. Since January 2017 Office Depot Europe is owned by Aurelius group, a European asset manager invested in over 60 companies. Office Depot Europe mainly sells products in the business to business market under two main brand names, Viking and Office Depot, spread over three sales channels: direct, contract and retail stores. Customers can buy products offline via call centers, e-mail and retail stores and online via the website.

2.1.1 Product

Office depot sells a variety of products in different categories. For example: Office supplies such as paper, desktop accessories and packaging supplies; Furniture such as chairs and desks; Facilities supplies such as catering, cleaning and health and safety essentials; Archiving such as folders, presentation binders and storage boxes; Technology such as computers, printers and cameras.

These products are offered in own brands which are: Office Depot and niceday, focusing on quality and price respectively. Office Depot also has three own brand lines focusing on quality for a specific type of product, these are: Foray, ativa and realspace focusing on writing products, technology and furniture respectively.

2.1.2 Departments

Today Office Depot is active in thirty European countries (Figure 2.1) with over 100 retail stores and subsidiaries served from distribution centers in: the Netherlands, Germany, France, Italy, Spain, Ireland and the United Kingdom.

Figure 2.1: Active countries Office Depot

Through European business partners customers are also served in Bosnia, Bulgaria, Croatia, Denmark, Estonia, Finland, Hungary, Latvia, Lithuania, Macedonia, Montenegro, Norway, Poland, Romania, Serbia and Slovenia.

[1] OEM = Original Equipment Manufacturer

2.2 Own brand sourcing process China

The thesis focusses on Office Depot's own brand items imported from China. These nearly 2500 different items are imported from almost 50 suppliers through 4 Chinese ports (Figure 2.2). From these ports the items are shipped towards either a Local Distribution Center (LDC) throughout Europe or to the Central Distribution Center (CDC) in Zwolle, the Netherlands where the products will be stored until a LDC needs the products. The ports, LDC's, CDC and head office of Office Depot Europe are represented in Figure 2.3.

Figure 2.2: Chinese suppliers and ports - Office Depot

Figure 2.3: European Ports, LDC's, DC and main office - Office Depot

Items shipped from china to LDC's follow a direct flow. Items shipped from China to the CDC and from the CDC to the LDC's follow an indirect flow. For direct deliveries from China to the LDC's and for deliveries to the CDC a monthly (4 week) review period with an average lead time of three months is maintained. For the indirect flow from the CDC to the LDC's a weekly review period with an average lead time of one week is maintained. This process can be seen in Figure 2.4.

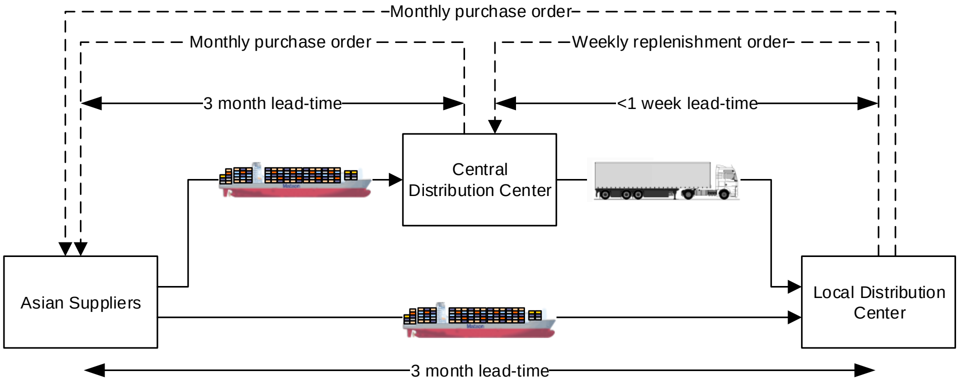


Figure 2.4: Material flow

3 Problem description

This chapter introduces the management dilemma and question developed by Office Depot, additionally some data is presented to make the problems more insightful. Based on these findings the research questions required to answer the management question have been developed. Then the project deliverables and boundaries are given. Finally this chapter concludes with the research methodology. The management dilemma and question developed by Office Depot are:

Management dilemma: *The supply chain cost and on hand inventory value of the private label products sourced in Asia is too high.*

Management question: *How should the supply chain of products sourced in Asia be setup in order to minimize supply chain cost and on hand inventory value while maintaining the current product availability level?*

The supply chain costs consist of several relevant factors. Costs are considered relevant when they can be influenced within the scope of this research. Some relevant costs are: transportation and storage costs. Possible cost savings can be achieved by switching between a direct or indirect flow, i.e. shipping directly to the LDC's or indirectly via the CDC. This will lead to different storage and transport costs due to for example order minima's. An additional possibility would be to use emergency and lateral shipments to reduce inventory while maintaining current product availability levels. However this would cause additional transportation costs.

During the period of April 2017 until September 2017 the average stock in the CDC was a little over € 5 million. By combining the average inventory with the average demand the stock turn per relevant LDC was determined. Office Depot has a target stock turn of 12. The actual average stock turn during the first 6 months of 2017 was 7, for only own brand items the average stock turn was below 4. Office Depot is aware that longer lead times yield lower stock turns but still thinks an improvement is possible. Table 3.1 shows that own brand items for warehouses go as high as a stock turn of 9.4, which suggest that improving stock turns is possible for the lower scoring warehouses.

Table 3.1: Average inventory, weekly demand and stock turns per year of items sourced in China.

LDC	Stock turns / year
Svanströms	9.34
Grossostheim	5.21
Lenzburg	1.40
Zwolle	5.85
Madrid	5.44
Northampton	5.44
Leicester	3.74
Ashton	2.62
Siziano	3.97
Total LDC's	3.68
CDC	4.76
Total	3.56

Note1: CDC demand is the LDC demand with an indirect flow plus the out of scope warehouses. Note2: In the average on hand inventory (AVG ONHND) only the physical inventory is taken into account, not the in transit inventory since this is not property of Office Depot due to the delivery terms with the vendors.

3.1 Research questions

Based on the problems described in the previous paragraph the following main research question was developed.

How should the supply chain of products sourced in Asia be setup in order to minimize supply chain cost and on hand inventory value while maintaining the current product availability level?

In order to answer this question the actual and preferred supply chain setup of Office Depot will be compared by calculating the expected supply chain performance of several setups. This will be done in several steps described in the following sub questions:

Sub question 1: What is the current supply chain setup for products sourced in Asia?
In order to give recommendations on changes in the supply chain setup the current setup is needed. Additionally this setup will be used as baseline for the expected cost. This current supply chain setup will be described by answering the following questions:

a. What is the current number of echelons?
b. What is the current transport method?
c. What is the current safety stock calculation?
d. What is the current reorder level calculation?
e. What is the current review period?
f. What is the current forecast method?

The number of echelons is needed to calculate the required safety stock for each location. The current transportation method is relevant because this influences the lead time and therefore the safety stock and required forecast period. The safety stock calculation is needed because this can be used to determine the safety stock which is needed for the reorder level. The reorder level is needed because this determines the required forecast period. Additionally the reorder level influences the product availability level which is part of the main research question. The review period is needed to calculate the reorder level and inventory value. Since reducing inventory value is part of the main research question investigating the influence of the review period is required. The forecast method is used for the reorder level because this influences the expected future inventory which triggers orders.

Sub question 2: What is the current supply chain performance for products sourced in Asia based on costs, inventory and product availability?
The current performance is needed to determine the correctness of the developed calculations since the expected and actual total costs should be roughly aligned when the actual setup is used in the calculations. Additionally several parameters of the actual performance are used for the calculations. The mean and standard deviation of the demand for example are required to calculate the safety stock.

a. What are the actual, relevant and influencable supply chain costs?
b. What is the actual inventory value?
c. What is the current product availability level based on fill and out of stock rate for the local DC's and OTIF[2] rate for the central DC?
d. What is the suppliers performance based on OTIF and mean, standard deviation and distribution of the lead time?
e. What is the mean, standard deviation and distribution of the demand?

[2] OTIF = On Time In Full

These costs are needed to check the correctness of the calculation model and as input for the calculation model since this question also determines which cost factors will be taken into account. Knowing the starting inventory value is required to determine the effect of the improvements. Since maintaining the current product availability is part of the main research question, the current availability level should be determined as target input for the calculations. The OTIF will be used to check whether the promised (contractual) delivery times are realized. In order to determine the safety stock the lead time variation is needed as well. The demand variation is, as mentioned before, part of the safety stock as well and needs to be determined.

Sub question 3: What would be the preferred supply chain setup for products sourced in Asia?
This question will answer the main research question by calculating the expected performance of different supply chain setups and selecting the setup with the best expected performance. The current setup will also be tested to check whether the calculations are realistic.

a. What would be the preferred number of echelons and in case of multiple echelons what would be the preferred location of the central warehouse?
b. What would be the preferred transport method?
c. What would be the preferred safety stock calculation?
d. What would be the preferred reorder level calculation?
e. What would be the preferred review period?
f. How could the current forecast method be improved?

The number of echelons is needed to calculate the required safety stock for each location. Additionally the location of a central warehouse influences the lead time between locations and therefore the safety stock. The transportation method is relevant since this influences the lead time and therefore the safety stock. The safety stock calculation is needed because this can be used to determine the safety stock of a random product which is needed for the reorder level. The reorder level is needed because this determines the required forecast period and average inventory level. Additionally the reorder level influences the product availability which is part of the main research question. The review period is required to calculate the reorder and safety stock level. Since reducing inventory is part of the main research question investigating the influence of the review period is required. The forecast method is used for the reorder level because this influences the expected stock in the future which triggers orders.

Sub question 4: What would be the preferred supply chain performance for products sourced in Asia based on costs and inventory while maintaining product availability?
Based on the calculations in sub question three each supply chain setup results in a certain supply chain performance. The setup with the best performance will be described here in order to give some more detailed insight in the effect of the changes in the supply chain setup.

a. What would be the preferred inventory value?
b. What would be the corresponding costs?

Sub question 5: What supply chain adjustments will result in the highest supply chain cost and/or inventory reduction?
Based on the results of sub question three and four the effect of each change in the supply chain setup can be determined which will result in the required changes and the steps in which the supply chain setup should be changed.

3.2 Project boundaries

For this project there are several boundaries defined in close consultation with Office Depot.

- This project focusses on the own brand products sourced in Asia for Office Depot Europe.
- The choice to stop selling certain products or to switch suppliers is out of scope.
- The project reviews most aspects of the supply chain and focusses on this so determining for example the most optimal forecasting method is out of scope, the research will accept near optimal solutions as well.
- There are two relevant previous researches at office depot which will be used as input for the current supply chain setup.
  - "Cost insights in a retailer's supply chain for multiple sourcing possibilities" (2015).
  - "Two-echelon Replenishment Policy with Periodic review, Lot sizing and Integral information for the region of UK & Ireland at Office Depot" (Vargas Suavita, 2012).
- Inventory carrying costs are out of scope for this research since these are not paid by Office Depot (see research proposal). Obsolescence assumed to be irrelevant for this research (research proposal).

3.3 Research Methodology

In order to answer the main and sub research questions several steps are needed. These are: literature review, Defining supply chain setup Office Depot and model development. An extended literature review has been done as separate course, a summary of the relevant literature will be given. Data will be gathered via employees of Office Depot and will be used to answer the first two sub questions. Based on the literature review a total cost function will be developed to calculate the expected supply chain costs based on the supply chain settings. By iteratively checking the expected costs of different settings a preferred setup will be chosen. This will be done via the following steps:

1. Test performance with current setup
2. Set safety stock with improved calculation
3. Use current supplier performance
4. Use improved forecast method
5. Test for preferred setup
   a. CDC
   b. Emergency shipments
   c. Lateral shipments
   d. Review period

The result of step one, the model with the actual supply chain setup, will be used to verify the accuracy of the model and the result of step 5, the performance with preferred supply chain setup, will be used to find potential improvements. Comparing these results will lead to an advice on how to improve the supply chain setup.

4 Literature research

In the literature research the required calculations for the investigation into the Chinese supply chain of Office Depot Europe are gathered. In this chapter the gathered literature will be briefly discussed. This literature focused on selecting a preferred supply chain flow, reorder and safety stock levels and choosing between different demand distributions. Additionally the impact of lateral and emergency shipments on the supply chain performance will be discussed.

Office Depot Europe imports items from the Chinese suppliers through two flows, direct and indirect. In the direct flow items are shipped directly from the suppliers towards the Local Distribution Centers (LDC's). In the indirect flow on the other hand items are shipped from the suppliers towards a Central Distribution Center (CDC) and based on demand these items are shipped to the LDC's throughout Europe. For each item and LDC the decision to ship either direct or indirect is made individually. These decisions however are not reviewed periodically, therefore this choice between direct and indirect flow has been investigated by Thomas Wijnberg (Cost insights in a retailer's supply chain for multiple sourcing possibilities, 2015).

4.1 Choosing between direct and indirect flow

Wijnberg (2015) suggested making this choice by selecting the flow with the lowest expected costs. The total cost function defined by Wijnberg (2015) consists of: acquisition, sea freight, road transport, inbound, outbound, storage, inventory carrying and obsolescence costs. However Wijnberg also evaluated the decision between different vendors, therefore some parameters might be irrelevant when only the flow is evaluated, for example the item price is not relevant for the decision since this is a fixed value when the vendor choice is fixed.

Masters (1993, pp. 178,179) describes taking holding, lost sales and transportation costs into account as "a more complete treatment" in inventory replenishment, in his research Masters assumes Poisson distributed demand. Swenseth & Godfrey (2002) claim that over fifty percent of the total logistics costs can be assigned to transportation. Based on this Swenseth & Godfrey (2002) studied the possibility to develop a transportation cost function that can be incorporated in inventory planning decisions. In this study Swenseth & Godfrey (2002) describe a logistic cost function with transportation costs only dependent on shipment size. Additionally Swenseth & Godfrey (2002) show that these transportation costs should not be ignored for JIT systems where normally more smaller shipments will be used without taking these costs into account. Huq *et al.* (2006) compared the effect of introducing a central warehouse, like Wijnberg (2015) they compared the expected costs of a system with and without a central warehouse. In this analysis the holding, handling and freight costs are taken into account. In contradiction to Wijnberg (2015) the transportation costs and lead times are considered equal for all warehouses. In order to include different transportation costs and lead times per warehouse could be done by substituting the fixed transportation costs by a vector with these costs and lead times defined per warehouse. Furthermore the decision to use a direct or indirect flow will be made per warehouse, as done by Huq *et al.* (2006) for the calculation of handling costs.

4.2 Reorder and safety stock levels

Furthermore this review will evaluate the safety stocks, reorder levels and reorder quantities at the different warehouses. For this evaluation the previous research by Vargas Suavita (Two-echelon Replenishment Policy with Periodic review, Lot sizing and Integral information for the region of UK & Ireland at Office Depot, 2012), further referred to as Suavita (2012) will be used as starting point.

Suavita (2012) used the research of Donselaar (1990) as main source and updated the calculations in order to take different review periods at the local and central warehouse into account. These updates were made based on personal conversations with Donselaar. Since this research will also takes this into account the updated calculations will be used. However Suavita (2012) assumes no lead time variance which, based on some first data insight, should be taken into account. Tallon (1993, pp. 192-193) and Chopra et al. (2004, p. 4) show a way to take lead time variance into account by updating the safety stock calculation.

In order to calculate the safety stock a service factor (k) has to be calculated based on the service level. This service level is based on the actual service level and will be calculated in paragraph 6.2. Office Depot calculates service for the central distribution center based on the so called time supply method, however in literature time supply has not been investigated as much as the shortage costing and service level approaches. The shortage costing approach has as disadvantage that it is difficult to calculate the costs of not having an item on hand when an order arrives since a decision has to be made whether a customer will wait for the item or buy decides to buy it somewhere else. Additionally the impact on customer satisfaction has to be evaluated since this could cause lost future customers/sales. Based on these two criteria, "the under-investigation of time supply safety stocks" and "the difficulty of calculating shortage costs", the service level approach is will be used.

In literature service levels are calculated with several procedures. There are three commonly used procedures. The first procedure is based on the stock out probability per cycle, i.e. the probability that a stock out occurs before the next order arrives. The second procedure is based on the fill rate, i.e. the percentage of demand satisfied from stock on hand. The third procedure is the ready rate, i.e. the fraction of time there is inventory on hand. These approaches are commonly referred to as S1, S2 and S3 or P1, P2 and P3 respectively for example in Dullaert (2007) or Donselaar and Broekmeulen (2014). For this research the P* will be used as reference.

Within Office Depot the P2 service level is used as performance measure for the local distribution centers. However this performance is measured based on the "line fill rate". This means that the service level is based on the number of completed order lines. For example if an order consists of 10 times item 1 and 5 times item 2 where the total demand of item 1 is delivered and only 4 out of 5 of item 2, the service level is 50% since only one out of two lines is completed. In planning however the "item fill rate" is used, which would have resulted in a 93.3% fill rate (14/15).

In historical literature the focus was on the P1 service level. The P2 service level however became more popular in more recent literature. In practice however P1 is still the most often used service level (Dullaert, Vernimmen, Aghezzaf, & Raa, 2007). The disadvantage of a P1 service level is that it does not take order quantities into account yielding a preference of small order sizes. Which is not preferred in long lead time systems with relatively high transportation costs. This is also supported by Dullaert et al. (2007) who evaluated the service level measurement for inventory systems with different transport modes and claimed that P2 service measure is "a more 'fair' service level specification when comparing transport modes from a logistics perspective".

With the service level the service factor (k) can be calculated. In order to calculate the service factor the distribution of the inventory position just after demand occurred is needed. When assuming that the inventory position just after demand is normally distributed the service factor k can be calculated as followed:

$$k = F^{-1}(\alpha)$$

$$with\ \alpha = service\ Level$$

However Donselaar (1990) claims that, under certain circumstances, a second approach should be considered. This approach is using a uniform distribution and should be used under the circumstance that $\frac{1}{12}Q_{i,j} \geq 4\big(l_j + R_{i,j}\big)\sigma_{i,j}^2$. In this case Donselaar (1990) suggests the following calculation:

$$k = (\alpha - 0.5) * \sqrt{12}$$

This approach was also adopted in the research of Suavita (2012) and seems valid. Donselaar (1990) showed that switching between a uniform and normal distribution based on his criteria is valid. He made several simulations with gamma distributed demand while the stock norms are determined based on normal or uniform distributed demand easing the calculations. This simulation showed that the proposed criteria to switch between uniform and normal distribution for the service factor yields the most accurate actual service level compared to the target service level. However this difference should be taken into account when modelling the actual situation.

Another part of this research is investigating the possibilities of using lateral and emergency shipments. This will impact the reorder and safety stock level calculations. Evers (1996, p. 120) claims that, for identical facilities with respect to all lead time and demand parameters, the cycle stock will remain the same. Therefore in inventory calculations only the safety stock levels will be affected in this kind of system.

For the use of lateral transshipments the approach of Naseraldin and Herer (2011, p. 443) is used who show that adding lateral transshipments to the inventory system affects the safety factor k at the local warehouses. They calculate the percentage of demand served by warehouse i and show how to calculate the expected service level of the total system based on the local service levels. They present the following calculation (with α instead of δ): $\hat{k} = k\sum\sqrt{\delta_j}$. Rewriting the equation gives a formula that can be used to calculate the local safety factors that are required to maintain the required overall service level. In order to use the calculation in the rest of the research some notation needs to be changed, resulting in the following calculation:

$$k = \frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}}$$

With,

- $N =$ Number of warehouses
- $\hat{k} = F^{-1}(\alpha) =$ Total target service level
- $\alpha =$ The required total stock out probability
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N}\mu_x} =$ Percentage of demand satisfied from warehouse i

Additionally Naseraldin and Herer (2011) introduce an optimization of the reorder levels while assuming equal demand at all locations, since this is not the case for this research this analysis is not used.

Finally Naseraldin and Herer (2011) provide a formula to calculate the expected costs. In this calculation they include the transshipment costs and quantities based on the number of warehouses. Since this calculation will be made per item, this can be used as the number of warehouses that sell the item since warehouses that do net sell a certain item will not have that item on stock.

For the use of emergency shipments several choices have to be made regarding the setup. Unfortunately the acquired literature focused on reactive emergency shipments instead of proactive. Alfredsson & Verrijdt (1999) describe a reactive system with lateral and emergency deliveries. The goal of this research however is proactive lateral and emergency (trans-) shipments. Having that in mind the calculations can be used as basis for the reactive emergency shipments. Alfredsson & Verrijdt (1999) describe three emergency replenishment options being lateral transshipment, direct delivery from central warehouse and emergency delivery from supplier. They describe this as different emergency replenishment options with different costs and lead times. Since the goal of this research also investigates comparable options this information can be used. Unfortunately they do not describe a way to calculate the base stock levels etc. for this options. Tagaras & Vlachos (2002) described a method that, with little adjustments, can be used for emergency shipments. This means a base stock level will be determined which orders the required amount to ensure delivery performance until the next order arrives.

After the inclusion of lateral and emergency shipments the remaining decision is which demand distribution to use in calculating the service factor. There the next paragraph will discuss the different demand distributions and how to choose between them.

4.3 Choice between gamma and normal data distribution

In literature several assumptions are made for the demand and lead time distributions in order to determine safety stock levels that are sufficient to cover the demand and lead time variation with a certain probability (service level). In literature the most commonly assumed distributions are normal, gamma and poison.

Selecting a certain distribution is mostly done via several assumptions since proving that a certain distribution has a better fit is quite difficult. A possible way to compare the fit of a certain distribution to the data is provided by Matlab. Two possible Matlab options are the negative log likelihood value and the Anderson Darling test. Matlab describes the negative log likelihood value as a scalar for the distribution fit to input data. The Anderson Darling test returns zero or one when the test respectively fails or succeeds to reject the null hypothesis at five percent significance (Null hypothesis: data is from a population that follows distribution x). Therefore when test returns 1 the data is not from a population that follows the tested distribution. Additionally the p value is returned ($p<5\%$ means null hypothesis is rejected). A possible way to select to best data distribution could be to run these two tests for each item and warehouse and select per item and warehouse the distribution with the best fit to the data. Then the method with the most “wins” is selected as distribution for the rest of the analysis. This method will be used to determine the demand and lead time distributions.

In order to select the best distribution some insights are needed in the three most commonly assumed distributions and the reasoning behind such assumptions. Therefore the previously mentioned Poisson, Normal and Gamma distribution are shortly discussed.

4.3.1 Poisson

The Poisson distribution which is a popular discrete distribution since it has equal mean and variance. Which simplifies several calculations and problems. Axsäter (2006, p. 85) claims that this is a good decision when $\sigma^2 / \mu \approx 1$, i.e. actual mean and variance are roughly equal. When this fraction is below 0.9 the suggest using binomial distribution and above 1.1 they suggest using a negative binomial distribution.

4.3.2 Normal

With high demand ($\lambda > 15$), it is more common to assume the normal distribution instead of the Poisson distribution since the Poisson probabilities are well approximated using the normal distribution and this is more convenient and efficient to model the demand by a continuous distribution (Axsäter, 2006, p. 85). Furthermore, according to the central limit theorem, the averages of a group of individual samples will be approximately "normally" distributed. Therefore assuming normally distributed demand is also convenient when the data is not Poisson distributed. The major disadvantage of the normal distribution is that it is allows negative values. The probability on negative values is relatively high when "the ratio σ/μ is not considerably less than 1" (Axsäter, 2006, p. 86).

4.3.3 Gamma

The assumption of a gamma distribution is popular because it has a non-negativity property which is convenient since negative demand or lead time is normally not possible. As mentioned, Axsäter (2006, p. 86) claims that the probability of negative demand is relatively high under the normal distribution when "the ratio σ/μ is not considerably less than 1". Therefore, when this holds, the gamma distribution would be preferred over the normal distribution. However when this would not hold another property of the gamma distribution could be used, this property is that when a gamma distribution is fitted to normal distributed data it will behave approximately as a normal distribution. However fitting a normal distribution to gamma distributed data could give more issues.

4.3.4 Other options

Another very commonly used approach is assuming a Compound Poisson distribution (Axsäter, 2006, p. 77), which means that the total demand is divided into two parts. The time between arrivals and the order size, both with its own lambda (mean and standard deviation). However this requires the data to be available in a way that allows the calculation of these two Poisson distributions. Another restriction is that with $\sigma^2 / \mu < 1$ it is not possible to model the demand process as compound Poisson (Axsäter, 2006, p. 80). However Axsäter (2006, p. 85) also states that "if the time period considered is long enough, the discrete demand from this compound Poisson process will become approximately normally distributed" this is also supported by the central limit theorem.

Finally, in inventory planning and control a common method to improve forecasting is removing trends, seasonality and outliers from data. Detrending and deseasonalizing data will be done for the demand distribution to make a correction based on historical data. However this is not possible for the lead times since there is less than a year of data available. Outliers however will be removed from the demand and lead time data. Outliers are data points of more than 1.5*interquartile range (Montgomery & Runger, 2014, pp. 209-210, 217) below or above the 1st or 3rd quartile respectively. The interquartile range is the distance between the 1st and 3rd quartile. The 1st and 3rd quartile are, in a dataset of 100 sorted data points, the 25th and 75th data point respectively. Another option would be considering data points more than 3*standard deviation from the mean as outliers.

4.3.5 Concluding

After reading the literature it already seems clear that the demand and lead time are either gamma or normally distributed since Poisson is approximately normally distributed over a longer time period (central limit theorem). However based on the non-negativity property of the gamma distribution it might be more interesting to consider using the gamma instead of the normal distribution. Based on the criteria "σ/μ is not considerably less than 1" given by Axsäter (2006, p. 86) the decision can be made. To ensure the correct distribution is selected the Matlab data fitting measurements (log likelihood and Anderson Darling) will be used. If this would not give a conclusive answer the property that a gamma distribution could quite easily be fitted to a normal distribution.

5 Current supply chain setup

In this chapter the current supply chain setup is discussed, which is needed to give recommendations on the required changes in the setup the supply chain. Additionally this setup will be used to determine the accuracy of the calculations because these results can be compared with the actual performance. The current supply chain setup is described in the number of echelons, current transportation method, safety stock calculation, reorder level calculation, review period and forecast method. These were determined via interviews with the employees of the own brand team on the current process. Secondly data was used to check this.

5.1 What is the current number of echelons?

Office depot currently has a two echelon supply chain with a central distribution center (CDC) in Zwolle, the Netherlands and local distribution centers (LDC) throughout Europe. The products can have two flows, either they are shipped directly to the LDC's or they are shipped to the CDC from where products are shipped towards the LDC's based on the latest demand flows. The decision to go for a direct or indirect flow is made based on the vendor agreed MOV's[3] and MOQ's[4]. If the orders for one warehouse are sufficiently large the orders are shipped directly, otherwise the orders are shipped indirect since sending indirect allows consolidating the demand of multiple vendors. These decisions are made by the own brand team.

5.2 What is the current transport method?

The transport method for replenishment from China is sea freight. Road transport is used for transportation from the CDC to the LDC's and between the LDC's. Sea freight has three options: 20 FT, 40 FT and 40 FT high cube (HC). The goal is to use 40 FT HC containers as much as possible since this is relatively the cheapest choice. However when the volume is too low smaller containers (20 or 40 FT) are used. This decision is made by partners in China based on the container fill rate. In Table 5.1 the container types are described. The maximal M^3 describes the size of the containers. The minimal M^3 is the contractual target minimal space used to ship a container and the average M^3 is the actual average. Based on these values the minimal and average fill rate are calculated to allow the comparison of the different container types. Finally the average pallets per container is given. When consolidation from different vendors would be needed to achieve the minimal fill rate the Chinese partners contact the own brand team that makes the final decision before an order is placed.

Table 5.1: Container information per container type

Container type	Min (M^3)	Max (M^3)	Minimal fill rate	Average (M^3)	Average fill rate	Average Pallets
20 FT	27.0	32.5	83%	25.5	78%	26
40 FT	57.0	67.0	85%	55.0	82%	51
40 FT HC	66.0	76.2	87%	65.5	86%	58

[3] MOV=Minimal Order Value
[4] MOQ=Minimal Order Quantity

5.3 What is the current safety stock calculation?

For the safety stock at the CDC there is no specific calculation available. The default value is 20 days safety stock which is increased when experience learns that 20 days is not sufficient. The local safety stock for own brand items is calculated in an external software program. An approximation of these calculations is known but there was not found an exact match when attempting to replicate the values from the external software program. The approximate safety stock calculation is:

$$SS = k\sqrt{\mu_L(\alpha\sigma_D^2) + \mu_D^2\sigma_L^2}$$

With,

- μ_L = Average lead time
- $\alpha\sigma_D^2$ = Smoothed demand variation
- μ_D = Average demand
- σ_L^2 = Lead time variation
- SS = Safety Stock
- k = Service factor

5.4 What is the current reorder level calculation?

The reorder levels for delivery to the CDC are based on the forecasted demand, the replenishment lead time, the safety stock and the review period. In these calculations the forecasted demand is used to calculate the required inventory. The lead time, safety stock in days and review period are combined to determine whether there is sufficient stock until the next review. The reorder levels for delivery to the LDC's (direct and indirect) are calculated in PRIME. However there is no information on these calculations available due to patents of the software provider.

5.5 What is the current review period?

The review period for the CDC and for direct orders to the LDC's is 4 weeks. The review period for indirect orders between the CDC and LDC's is one week.

5.6 What is the current forecast method?

Forecasting is based on an access script that can makes a forecast per SKU per LDC. This script is ran for most LDC's and the demand is combined to forecast the CDC demand. The results are submitted to the LDC's so they can review the forecasted demand. The LDC's that are excluded are Czech and Sweden, these countries submit their own forecast based on an unknown method.

In Figure 5.1 the complete supply chain setup can be seen. With the blue line representing the direct flow when it does not equal the indirect flow.

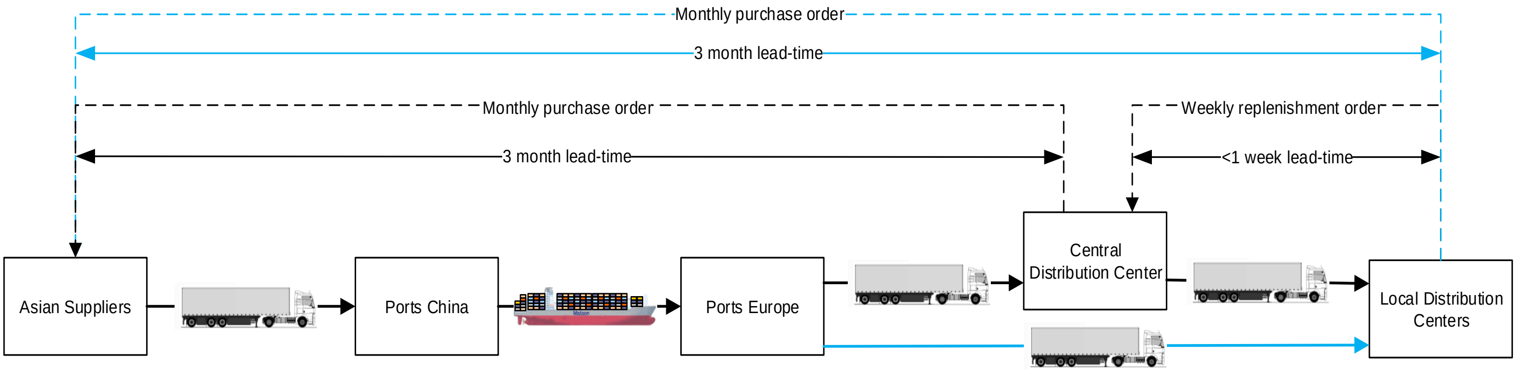


Figure 5.1: Supply chain setup Office Depot

6 Current supply chain costs and performance

In this chapter the current supply chain costs and performance has been described based on Sub question 2: "What is the current supply chain performance for products sourced in Asia based on costs, inventory and product availability?". First the supply chain costs are described, followed by the inventory value, product availability, supplier statistics and demand statistics. The chapter will be concluded with a visual representation of the supply chain setup and performance in paragraph 6.5.

6.1 Actual supply chain costs

For this research the actual, relevant and influencable supply chain costs are transportation costs from vendor to DC's (CDC and LDC) and from the CDC to the LDC's, inbound, outbound and inventory costs at CDC and inventory costs LDC. Material costs at vendor are non-influential but relevant costs because these are required to calculate inventory costs. Inbound and outbound costs at LDC are not relevant for this research because they are out of scope and considered non-influential.

6.1.1 Transportation costs vendor to distribution center

Transportation of items from the vendors to the DC's is outsourced to a sea freight carrier. This carrier provided a rate card which shows the costs for shipping a container of a certain size to a specific warehouse in Europe. From all costs described on this rate card only the costs per container are taken into account since cost per B/L (bill of lading) and shipment are assumed as non influencable for this research. Demurrage costs and other surcharges are ignored since these are also out of scope for this research. In Table 6.1 one complete rate card without costs is given as example. The bold costs are the costs considered relevant and influencable for this research.

Table 6.1: Example rate card provided by sea freight carrier

Type of costs	Per
Ocean Freight validity until 31/12/2017	**Container**
THC / CSC Container Handling at Port of Arrival	**Container**
ISPS Charge at Destination	**Container**
Import Customs Formalities (unlimited number of line items)	Shipment
Delivery Charge (rail/truck)	**Container**
Import Handling	B/L
Delivery surcharge outside office hours (19:00 - 06:00)	Container
Waiting Charge (Delivery)*	Per hour

The remaining relevant costs are: 'Ocean Freight', 'THC / CSC Container Handling at Port of ARRIVAL', 'ISPS Charge at Destination' and 'Delivery Charge'. The sea freight carrier also provided the actual shipped containers and costs over the first 8.5 months of 2017 specified per cost type. The containers per destination and container type are shown in Table 6.2. Based on the relevant costs and number of containers shipped the contract based costs have been calculated.

Table 6.2: Actual containers shipped per container type and destination

Destinations	**Ashton**	**CDC**	**Grossostheim**	**Leicester**	**Madrid**	**Siziano**	**Svanströms**	**Zwolle**	**Total**
20 FT	31	52	26	21	12	3	1	1	147
40 FT	42	86	32	37	9	5	1	8	220
40 FT HC	47	101	48	82	0	9	0	7	294

6.1.2 Transportation costs from CDC to LDC's

The items are shipped from the CDC to the LDC's by an external carrier. Based on the contract with this carrier the expected costs of this flow can be calculated and compared with the actual costs to check the correctness of the calculations. Table 6.3 shows the percentage difference resulting from this comparison. The actuals are based on the actual payed costs. Calculated costs are the expected costs based on the actual shipped items, the items per pallet and pallets per truck. Both, actual and calculated costs are based on the first 9 months of 2017, divided by 9 multiplied with 12 to get an estimate of the annual costs. The estimated costs are accepted despite the high difference in total costs (14%). This is accepted since it is the best approximation that was possible. This comparison was quite difficult since a normal truck can ship 33 pallets, however sometimes pallets can be stacked. On requirements for stacking these items there was little information. Therefore the correction with the lowest cost difference is selected. This is a correction of 0.8 for the total pallets, meaning that 1 out of 5 pallets is stacked on top of other pallets. Additional due to the possibility of sending mixed pallets a correction of a minimal pallet quantity used per item of 0.1 is used.

Table 6.3: Differences between actual and calculated road transportation costs from CDC to LDC's

Destinations	Costs	Pallets	Trucks
Ashton	6%	-5%	0%
Grossostheim	-3%	-6%	0%
Leicester	8%	-2%	16%
Lenzburg	29%	44%	0%
Madrid	32%	24%	35%
Northampton	-36%	1%	7%
Siziano	23%	32%	8%
Svanströms	12%	-5%	18%
Total	**14%**	**6%**	**11%**

6.1.3 Storage costs

The financial department of Office Depot uses 8.5% interest on the annual inventory value. Additionally holding costs for the used space has to be payt. For the central DC in Zwolle these costs are determined by the financial department at a fixed percentage of the total warehouse costs. For the other DC's this percentage is unknown since there is no split between CDC and non CDC items there. Therefore the costs per square meter have been calculated for each warehouse. These costs are compared with the costs per square meter in Zwolle and for the difference a correction rate is calculated (Table 6.4). Then the costs per pallet in Zwolle is calculated and multiplied with the correction rate to get an estimate of the costs per pallet in the other countries.

Table 6.4: Correction rates for storage costs CDC vs LDC's

	%
CDC	100.00%
Zwolle	100.00%
Grossostheim	99.78%
Ashton	96.08%
Leicester	150.57%
Northampton	58.76%
Madrid	127.12%
Siziano	73.83%
Lenzburg	174.10%
Svanströms	144.20%

6.1.4 Inbound and outbound CDC

The inbound and outbound costs for the CDC are calculated based on the registered hours. Fixed costs for Payroll, Rent & lease (Forklifts, storage racks, etc.) and Supplies (Cartons, etc.) are taken into account. Additionally costs are made for quality checks and maintenance. Quality means: Checking inventory mismatch (90%) and Measuring new items (10%). Since quality checks have to be made regardless the warehouse these hours are ignored. Maintenance hours are less than 1% of the total hours and will therefore be ignored as well. The hours are given in Table 6.5.

Table 6.5: Average booked hours and costs CDC

	Hours per week
Inbound	127.6
Outbound	180.4
Quality	23.2
Maintenance	0.4
Total	331.6

6.1.5 Actual inventory value

The average inventory value is based on the actual inventory levels of the first nine months of 2017. This resulted in the average inventory on hand, since some items are out of scope these are removed from the average inventory. However this was not possible for the CDC due to lack of data availability. Visually the on hand inventory, including out of scope items, can be seen in Figure 6.1.

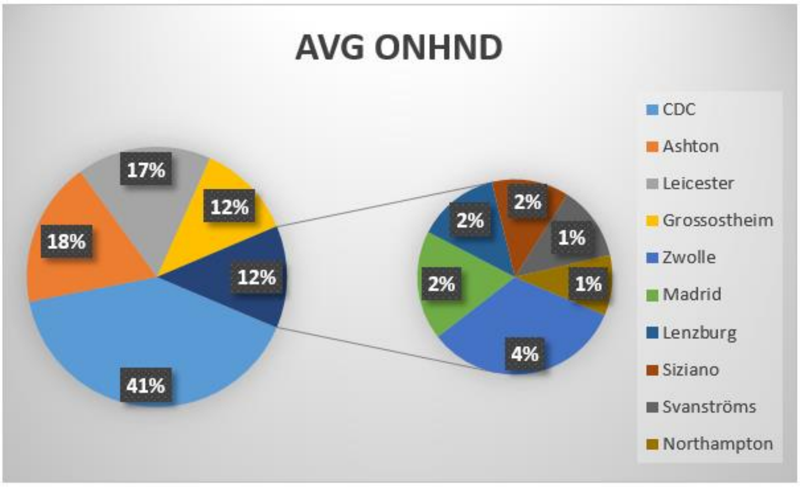


Figure 6.1: On hand inventory

Based on the same data set the safety stock levels were retrieved. From these safety stock levels the average days of safety stock and the value of the safety stock have been calculated (Table 6.6). Surprising in these results is that the safety stock for direct items is only 0.2 days longer than the safety stock for indirect items. While the lead time for indirect items is roughly 1 week and the lead time for direct items is roughly 10 weeks. This suggests there

Table 6.6: Average safety stock value in days and euro

	Calendar days
LDC Indirect	10.3
LDC Direct	10.5
LDC Total	10.4
CDC	27.8
Total	32.0

6.1.6 Cost summary

A summary of the costs factors for the different flows (direct and indirect) has been calculated. In Table 6.7 these costs are given as percentage of the total costs to provide some insight in the differences between the costs for direct and indirect items.

Table 6.7: Cost percentage summary

% of total costs	Indirect	Direct	Total
Annual inventory costs (8.5%)	2.53%	1.72%	1.98%
Costs storage space	3.13%	2.71%	2.85%
Annual sea transport costs	4.91%	4.42%	4.58%
Annual CDC costs (in/outbound)	3.27%	0.00%	1.06%
Annual road transport	2.87%	0.00%	0.93%
Supply chain costs/Total costs	16.71%	8.85%	11.40%

6.2 Actual service level DC's

The LDC's have an overall line fill rate of 98.15% over the past 6 years and 98.66% since 2015. The fill rate history can be seen in Figure 6.2. Additionally the stock out rate of the LDC's over the past 6 months has been calculated, which was 6.30%. Finally OTIF of the CDC has been calculated which was 75% over the past year.

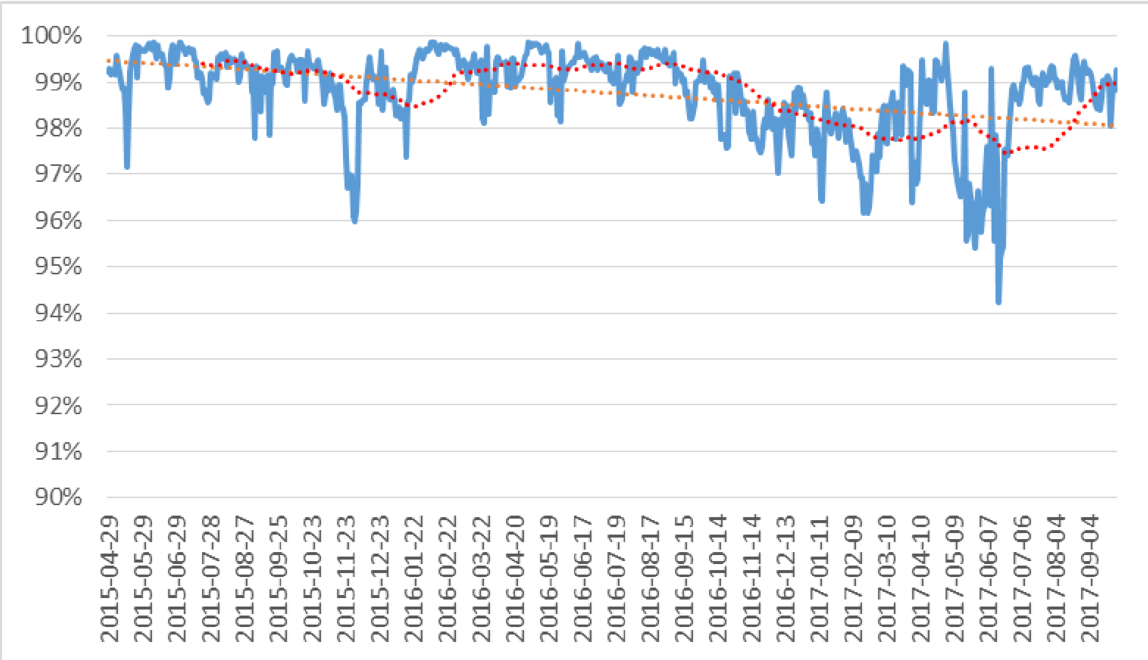


Figure 6.2: Line fill rate CDC items

6.3 Actual lead time distribution and parameters

In Table 6.8 the supplier performance based on average lead time and standard deviation of the lead time are given per destination. A distinction is made between the vendor lead time and performance and the carrier lead time and performance. The out of scope warehouses are taken into account as well since this can be used as additional information for the vendor lead time.

Table 6.8: Actual performance vendors and sea freight carrier

	Vendor production time		Carrier transportation time		Overall lead time		Count
	Actual	σ	Actual	σ	Actual	σ	
ALCALA DE HENARES	32.00	6.80	52.29	7.94	84.29	8.77	185
ASHTON-UNDER-LYNE	40.33	18.12	49.03	10.74	89.36	16.93	1839
DUBLIN	44.53	17.94	45.73	7.73	90.26	18.14	2435
GROSSOSTHEIM	24.78	5.72	48.13	4.31	72.91	7.78	54
HOSTIVICE	45.00	23.98	52.02	9.60	97.03	21.96	2360
LEICESTER	35.79	6.30	50.25	4.39	86.04	8.60	24
LENZBURG	30.91	9.29	48.11	7.72	79.02	10.66	350
MEUNG-SUR-LOIRE	29.92	9.99	52.08	9.06	82.00	10.92	299
SENLIS	30.35	10.43	54.25	12.16	84.60	12.14	77
SIZIANO	30.74	8.88	54.08	9.78	84.82	12.36	284
ST MARTIN DE CRAU	51.71	11.34	64.29	0.76	116.00	10.58	7
STRANGNAS	48.14	19.72	38.66	2.53	86.80	18.48	333
ZWOLLE	49.51	18.45	43.30	6.37	92.81	17.76	3274
ZWOLLE CDC	43.94	19.66	47.29	9.22	91.23	18.61	11521
Total	32.00	6.80	52.29	7.94	84.29	8.77	185

Lead time distribution:

The lead time distribution is divided in two parts. The production lead time and the transportation lead time since the vendors are responsible for production and the carrier for the transportation. The production lead time is determined per vendor and the transportation lead time per port-warehouse combination. This was done to ensure having the correct lead times for the correct flows since a shipment from, for example, Shanghai to Madrid will not have the same lead time as a shipment from Shanghai to Grossostheim.

Before determining whether these parts follow a normal or gamma distribution the outliers were removed. Outliers are, as described in paragraph 4.3.4, data points of more than 1.5*interquartile range (Montgomery & Runger, 2014, pp. 209-210, 217) below or above the 1st or 3rd quartile respectively. The interquartile range is the difference between the 1st and 3rd quartile. The 1st and 3rd quartile are, in a dataset of 100 data points sorted from lowest to highest, the 25th and 75th data point respectively. Removing the trend and seasonality as well was not possible due to the small data set that was available (<1 year).

Based on the analysis in section 4.3 the lead time is expected to be either normally or gamma distributed which will be determined by fitting the data to both distributions and comparing the Log-Likelihood and Anderson darling scores. In this analysis the performance measures (Log-likelihood, andersondarling10 and AD P-Value) are calculated individually for each vendor and port-warehouse combination to avoid one bad performing flow affecting the overall result. Figure 6.4 gives the Anderson darling p-value and log likelihood score of each individual flow for the gamma and normal distribution.

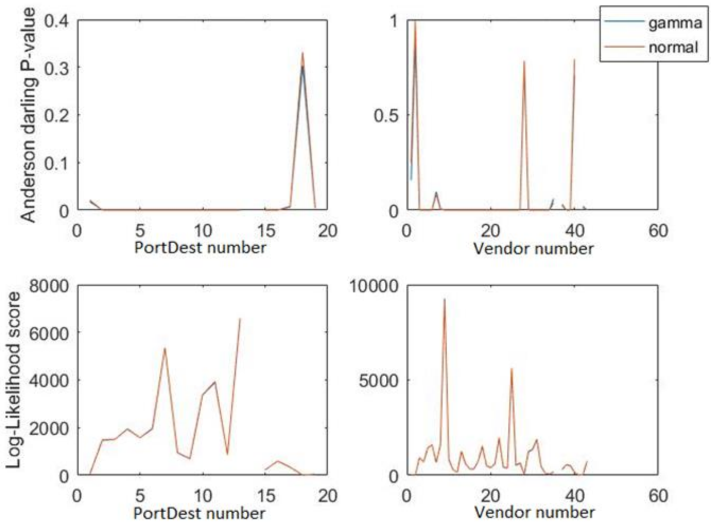


Figure 6.3: AD and LLH scores of the gamma and normal distribution

Figure 6.4 shows barely any difference in the scores of the gamma and normal distribution. Therefore the percentage difference between the scores is calculated with: $\frac{(gamma-normal)}{normal}$. This gave the percentage difference scores as shown in Figure 6.4. Based on which the average absolute percentage differences have been calculated (Table 6.9). The table shows that the average absolute percentage difference based on the log likelihood score is below two percent. For the Anderson darling test this difference is higher, however looking at the plots of the Anderson darling P-value in Figure 6.4 and Figure 6.4 gives that this difference is mostly due to small P-values (way below 5%), meaning that in that case both distributions are rejected.

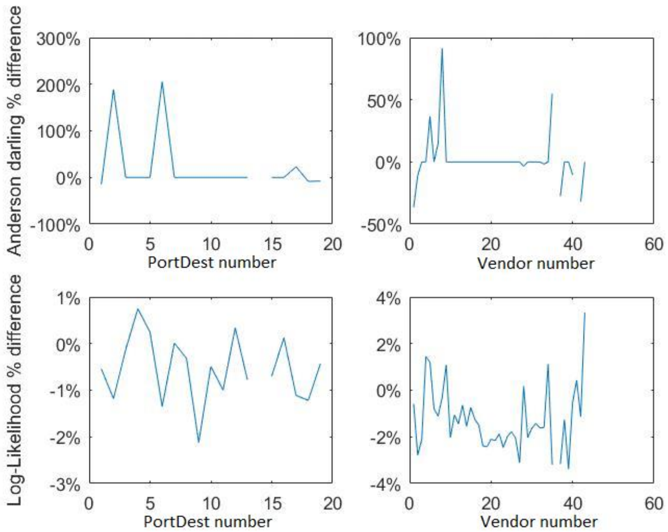


Figure 6.4: Percentage difference in scores between the gamma and normal distribution

Table 6.9: Average absolute percentage difference

	Port Destination	Vendor
Anderson Darling	24.88%	7.81%
Log-Likelihood	0.71%	1.67%

As mentioned in section 4.3 the Anderson darling test also gives a 1 or 0 next to the p-value when the null hypothesis that the demand follows a certain distribution is rejected or accepted respectively. Therefore the rejection percentage of each distribution could be calculated for the vendor production and transportation time respectively (Table 6.12). In addition to this measure the individual scores have been compared per vendor/port-warehouse and the "wins" for each distribution are counted, as described in section 4.3. By dividing the "wins" of the gamma by the "wins" of the normal distribution a percentage is calculated representing the percentage of times the gamma distribution is preferred over the normal distribution. It is possible to have a tie in which case no distribution "wins". The percentage that gamma is preferred over the normal distribution is therefore only based on the non-equal results. The percentage of times the gamma distribution was preferred over the normal distribution and the percentage of time there was a difference ("based on X% of the data") are shown in Table 6.10 and Table 6.11 for the vendor production time and port-warehouse transportation time.

Table 6.10: Result of fitting gamma and normal distribution to actual vendor production time

Production per vendor (43)	Log-Likelihood	Andersondarling10	AD P-Value
Gamma better than Normal %	83%	100%	38%
Based on X % of vendors	98%	7%	30%

Table 6.11: Result of fitting gamma and normal distribution to actual sea transportation time

Transportation per Port-warehouse (19)	Log-Likelihood	Andersondarling10	AD P-Value
Gamma better than Normal %	72%	100%	43%
Based on X % of port-warehouses	95%	5%	37%

Table 6.12: AndersonDarling10 rejection rate

AndersonDarling10 rejection rate	Gamma	Normal
Production per vendor (43)	81%	88%
Transportation per Port-warehouse (19)	89%	95%

Form the above tables several conclusions can be drawn.

- Based on the AndersonDarling10 the gamma is never worse than the normal distribution. However there only was a preference in both scores in 7 and 5% of the cases.
- Based on the Log-Likelihood the gamma was preferred over the normal distribution, based on 98 and 95% of the cases.
- Based on the AD P-value the gamma was not preferred over the normal distribution, contradicting the result of the Log-Likelihood score. However this difference was only based on 30 and 37% of the cases.
- Based on the rejection rates both fits are rejected for over 80% of the cases.

This analysis shows a slight preference for the gamma distribution, however the differences between both distributions are small. Furthermore the Anderson darling test rejects both fits with 5% significance in over 80% of the cases. Therefore it cannot be concluded that either one of the distributions is the correct distribution for the data. To avoid making the calculations more complex than necessary, the normal distribution will be used in the rest of this research.

6.4 Actual demand distribution and parameters

Before determining whether the demand follows a normal or gamma distribution the outliers, trend and seasonality were removed as described in sub-section 4.3.4. Figure 6.5 shows this effect for one item indicating that, for that item, it made sense to remove the trend and outliers. The trend can be seen in Figure 6.6 which contains the trend of all items. Seasonality was removed by dividing the entire year into 13 periods of 4 weeks. Figure 6.7 shows the seasonality of one item. This all combined shows that it makes sense for multiple items to remove outliers, trends and seasonality.

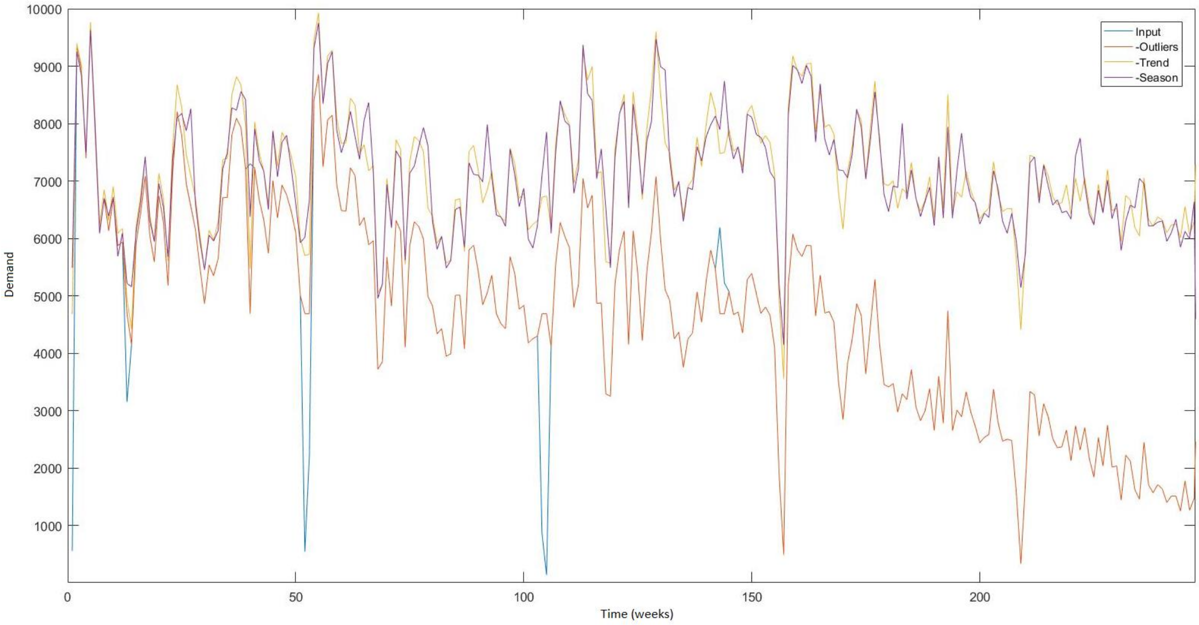


Figure 6.5: Actual demand for arbitrary item {excluding outliers, trend and seasonality per step}

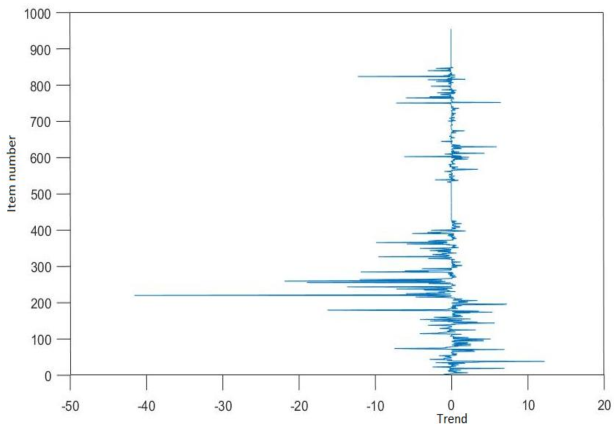


Figure 6.6: Trend all items

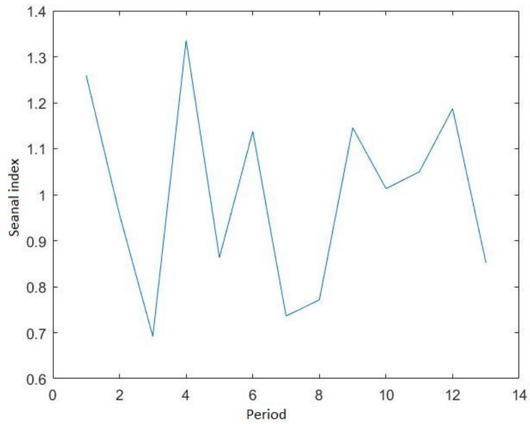


Figure 6.7: Seasonality index arbitrary item

After the trend, seasonality and outliers were removed the data was fitted to a normal and gamma distribution to select the distribution with the best fit. This process was similar to the process for fitting the lead time distribution used in the previous section. Table 6.13 shows the percentage of times the gamma distribution was preferred over the normal distribution and the percentage of time there was a difference ("based on X% of the data"). Table 6.14 shows the rejection rate based on the Anderson darling score. Additionally the distribution was tested after dividing the items into 4 groups (based on demand) with group 4 having the highest demand (Table 6.15).

Table 6.13: Result of fitting gamma and normal distribution to actual demand

	Log-Likelihood	Andersondarling10	AD P-Value
Gamma better than Normal %	60%	3%	3%
Based on X % of port-warehouses	41%	8%	36%

Table 6.14: AndersonDarling10 rejection rate

Rejection rate	Gamma	Normal
Production per vendor (43)	98%	80%

Table 6.15: Gamma vs normal per demand group based on lowest to highest demand

Gamma better than Normal %	Log-Likelihood	Andersondarling10	AD P-Value
Group 1	51%	1%	3%
Group 2	50%	5%	4%
Group 3	76%	2%	4%
Group 4	63%	2%	3%
Total	60%	3%	3%

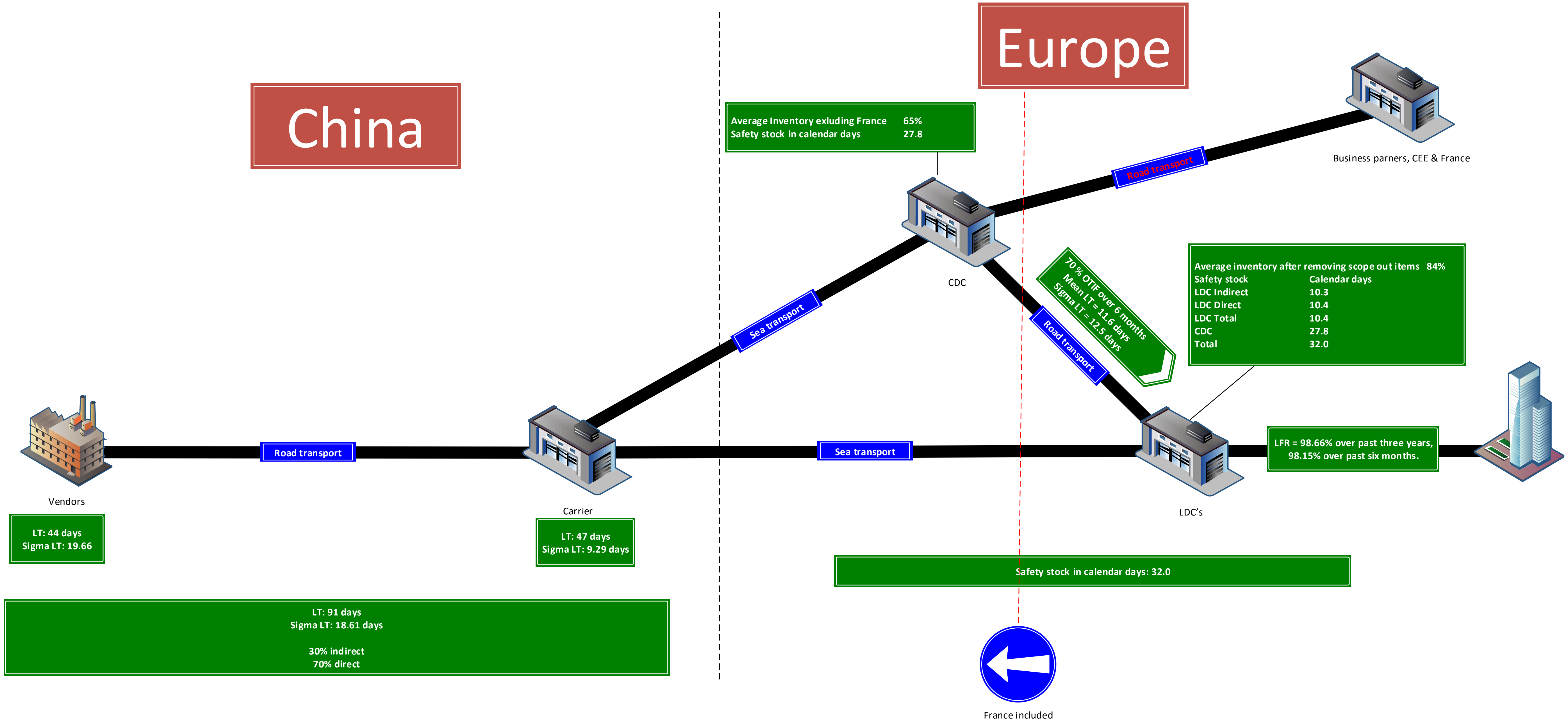
From the above tables several conclusions can be drawn:

- Based on the AndersonDarling10 the gamma is only preferred for 3% of the items. However there only was a preference in 8% of the cases.
- Based on the Log-Likelihood the gamma is preferred in 60% of the cases. However there only was a preference in 41% of the cases.
- Based on the AndersonDarling P-value gamma is only preferred in 3% of the cases. However there only was a preference in 36% of the cases.
- The rejection rate shows that gamma is rejected in 98% of the cases and the normal distribution is rejected 80% of the cases.
- Looking to the specific groups also gives a slight preference for the gamma distribution based on the Log-Likelihood score and a clear preference for the normal distribution based on the anderson darling results.

These conclusions are contradicting. Therefore no conclusive decision between the distributions can be made. To avoid making the calculations more complex than necessary, the normal distribution will be used in the rest of this research.

Since the current forecasting method is partially based on an access script of which gaining insight was not possible within the time frame of this research the correction for trend and seasonality is seen as “new” forecasting method. Removing the trend and seasonality reduces demand variation (what would normally be captured in a forecast).

6.5 Concluding visual supply chain performance



7 Preferred supply chain setup calculations and methods

The preferred setup has been defined as the setup with the best performance based on inventory value and supply chain costs. Inventory value is included in the supply chain cost calculations which allows to focus on cost minimization. In the main research question keeping the current service level is mentioned as goal. Therefore the preferred supply chain setup is the supply chain setup with the lowest costs with the current service level. In order to select the best settings a Matlab model has been developed that calculates the expected annual costs based on certain supply chain setups. The model with the lowest costs will be selected as preferred supply chain setup. In order to build this model several calculations and methods have been developed which take the relevant cost factors into account. The first part is determining the preferred flow, i.e. whether the CDC should be used and for which items. Then the influence of adding emergency and lateral shipments will be evaluated. Therefore the first section of this chapter explains how the calculations used in this model have been developed followed by the methods used to determine the preferred settings on item flow, lateral shipments and emergency shipments. In the development of the calculations several assumptions were required. These assumptions are:

1. Normally distributed demand and lead time
   This assumption is supported with data analysis
2. Stochastic and independent demand for consecutive periods and different warehouses and items
3. Average demand is equal for each month of the year
   Trend and seasonality are removed before the cost calculations assuming that this deviation is captured in the forecast method
4. All demand that cannot be satisfied directly from stock is backordered
5. There are no constraints regarding storage capacities
6. Products are non-perishable
7. Product values are constant
8. Shipping price (per truck and container) is dependent on shipment size
9. Shipping two times two pallets is never less expensive than shipping four pallets at once. For truck and container shipments

7.1 Total expected cost function

The preferred item flow will be selected based on the total expected annual costs. After comparing the different models and approaches described in the literature analysis in section 4.1 the total cost function parameters developed by Wijnberg (2015) are updated in order to allow the inclusion of lateral and emergency shipments and in order to include lead time variance into the safety stock calculations suggested by Suavita (2012). This resulted in the following total cost function (for extended analysis development steps see Appendix I):

$$SCC = \sum_{j=1}^{J} TC_j + IBC_j + SC_j + OBC_j \tag{1}$$

With:

- SCC = Annual Supply Chain Costs
- J = Total number of local warehouses + CDC
- j = Warehouse number {1,…,J}
- TC_j = Annual transportation costs to warehouse j
- IBC_j = Annual inbound costs at warehouse j
- SC_j = Annual storage costs at warehouse j
- OBC_j = Annual outbound costs at warehouse j

In the following sub sections the calculations for these parameters will be described, starting with the storage costs since some of the calculations are required for the transportation, inbound and outbound costs.

7.1.1 Storage costs

The storage costs consist of two parts; the opportunity costs, i.e. the money invested in inventory; and the cost of storage for the warehouse space used for the items. This is based on the assumption that if the items would not have been there the money and storage space could have been used for other purposes. Therefore the calculation is as follows:

$$SC_j = \sum_{i=1}^{I} \bar{I}_{ij} * \left((Price_i * interest) + \frac{EuroPerPallet_j}{PalUn_i} \right) \tag{2}$$

$$\bar{I}_{ij} = \max(SS_{ij}, SSE_{ij}) + \frac{\mu_{ij} * R_{ij}}{2} \tag{3}$$

With:

- I = Total number of items
- i = Item number {1,…,I}
- $\bar{I}_{ij}$ = Average inventory of item i at warehouse j
- $Price_i$ = Purchase price of item i
- $interest$ = Interest percentage
- $EuroPerPallet_j$ = Costs per year for storing 1 pallet
- $PalUn_i$ = Items of type i per pallet
- SS_{ij} = Safety stock of item i at warehouse j
- SSE_{ij} = Safety stock for emergency shipments of item i to warehouse j
- μ_{ij} = Average weekly demand of item i at warehouse j
- R_{ij} = Review period of item i at warehouse j

A. Safety stock

The safety stock level (SS_{ij}) is calculated with the research of Suavita (2012) as starting point. Suavita (2012) used the research of Donselaar (1990) as main source and updated the calculations to take different review periods at the local and central warehouse into account. These updates are based on personal conversations between Suavita and Donselaar. Since this research has different review periods between the CDC and LDC's as well the updated formulas have been used. However there have been two updates on the calculations provided by Suavita.

The first update was required since Suavita calculated the variance of imbalance ($\sigma^2_{ij,imb}$) as $\frac{1}{12}Q^2$. However, according to Donselaar (1990), this only holds when one item at the central warehouse can be used for different final items, which is not the case. Donselaar (1990) provided several calculations for the variance of imbalance, one for systems without a depot and one for systems with a depot, i.e. for items with direct and indirect delivery respectively. In these calculations N was described as the number of divergent items, i.e. items that can be used for multiple final products N equals 1. This yielded in a variance of imbalance of zero for both flow options. Therefore this factor has been removed from the calculations.

The second update on the safety stock calculation was including the lead time variance into the safety stock calculations. This was required since these items have a rather long lead time and first data analysis showed a rather high lead time variance. This is supported in common literature which suggest that longer lead times lead to higher lead time variances. Tallon (1993, pp. 192-193) suggests taking lead time variance into account by updating the safety stock calculation. This approach was also used by Chopra et al. (2004, p. 4). Including these changes resulted into the following safety stock calculations for the local and central DC's:

$$SS_{ij} = -\frac{1}{2}Q_{ij} + k * \sqrt{\frac{1}{12}Q_{ij}^2 + Var_{ij}}\ with\ j < J \tag{4}$$

$$Var_{ij} = (l_j + R_{ij})\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2\ with\ j < J \tag{5}$$

$$SS_{iJ} = -\frac{1}{2}Q_{i,J} + k * \sqrt{\frac{1}{12} * Q_{iJ}^2 + Var_{iJ}} \tag{6}$$

$$Var_{iJ} = \sum_{j=1}^{J-1}\left[\left(L_i + R_{iJ} - R_{ij}\right) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{(l_j + R_{ij})\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2 \tag{7}$$

With:

- Q_{ij} = Order multiple for item i at warehouse j (note: is not the same Q as in previous chapter)
- Var_{ij} = Variance component of item i at warehouse j
- l_j = Lead time for warehouse j
- σ_{ij}^2 = Demand variation of item i at warehouse j
- σ_{Lij}^2 = Lead time variance for ordering item i at the corresponding vendor with delivery to warehouse j
- σ_{LJj}^2 = Lead time variance for shipping from central warehouse J to warehouse j
- L_i = Lead time of item i
- k = Target service factor with the impact of the allowed lateral and emergency shipments
- In the calculation for Var_{iJ} only the warehouses that have an indirect flow for item i are summed.

The calculations for the target service factor will be explained in several steps since the impact of selecting a direct or indirect flow, allowing lateral shipments and allowing emergency shipments have to be evaluated. In order to include these effects the impact of selecting an indirect flow is evaluated first, then the impact of lateral shipments is evaluated, followed by the impact of emergency shipments. These results will be combined to form the overall calculation that takes the item flow, lateral shipments and emergency shipments into account.

In order to calculate the target service factor (k) the target service level (α) is needed. The service level is the probability that demand can be satisfied from stock, i.e. the probability that the inventory is greater or equal to zero. In this research it is assumed that this probability is normally distributed. However Donselaar (1990) claims that, under certain circumstances, a second approach should be considered. This approach is using a uniform distribution and should be used under the circumstance that $\frac{1}{12}Q_{ij}^2 \geq 4 * VAR_{ij}$. Additionally Suavita (2012) reported a method developed by Donselaar which allows different review periods at the local and central warehouses. Based on this method α is updated to α' to correct for the differences in review period at the local and central warehouses for indirect shipments. For direct shipments no update was required and therefore $\alpha' = \alpha$ (9). These updates result in the following calculations:

$$k = \begin{cases} F^{-1}(\alpha') & if\ \frac{1}{12}Q_{ij}^2 < 4 * VAR_{ij} \\ (\alpha' - 0.5) * \sqrt{12}\ if & \frac{1}{12}Q_{ij}^2 \geq 4 * VAR_{ij} \end{cases} \tag{8}$$

$$\alpha' = \begin{cases} \frac{2 * R_{iJ} * \alpha + R_{ij}}{2 * R_{iJ} + R_{ij}} & if\ indirect\ flow \\ \alpha & if\ direct\ flow \end{cases} \tag{9}$$

With,

- α' = Updated service level for different review period at CDC and LDC
- α= The required overall service level

B. Lateral shipments

Naseraldin and Herer (2011, p. 443) have shown that adding lateral transshipments to the inventory system affect the safety factor k at the warehouses. They have given a formula to determine the expected overall safety factor, inversing this function gives the required local safety factor with lateral shipments. Therefore $\hat{k}$ is defined as the overall target service level and k as the local service level. For this calculation they assumed the following:

1. demand on non-overlapping line segments is independent
2. it is beneficial to use lateral transshipments, i.e., the lateral transshipment cost is less than the sum of the holding and shortage costs
3. the lateral transshipment cost is linear in the volume and independent of distance

The only worrying assumption is the second one since there are no shortage costs, however the goal is using the optimal number of shipments, therefore if holding costs would be lower than shipment costs no lateral shipments would occur. Therefore this assumption is accepted. Based on this the formula to update k depending on the allowance of lateral shipments is:

$$k = \begin{cases} \frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}} & if\ lat_{ij} \\ \hat{k} & otherwise \end{cases} \tag{10}$$

With:

- k = Target service factor with lateral shipments
- N = Number of warehouses
- $\hat{k}$ = Target service factor without lateral shipments
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N} \mu_x}$ = Percentage of demand satisfied from warehouse i
- lat_{ij} = True if lateral shipment are allowed

C. *Emergency shipments*

In order to determine the effect of emergency shipments on storage costs the idea of Tagaras & Vlachos (2002) on including lateral shipments has been used. They defined two base stock levels per warehouse, the *regular base stock level* and the *reserve base stock level*. The idea behind this method is that the lateral shipment should only cover the demand shortage until the next regular order arrives. Since in the case the same idea is used for emergency shipments this base stock calculation can be used. This would give that the emergency base stock level is should be sufficient to fulfill the demand until the regular order arrives. However in this particular case there are overlapping periods, i.e. a new order is placed before the previous order is delivered (R<L) this also hold for the emergency shipments since the emergency lead time is larger than the review period as well. Therefore the emergency base stock level calculation is adapted by switching the review period with the lead time. Additionally the order will be placed at the same time of the regular orders causing the t to be zero. Therefore the base stock calculations are:

$$S_{ij} = \mu_{ij}(L_{ij} + R_{ij}) + SS_{ij} \tag{11}$$

$$s_{ij} = \mu_i(L_{ij}) + SSE_{ij} \tag{12}$$

Therefore the emergency safety stock calculation and updated service factor are:

$$SSE_{ij} = -\frac{1}{2}Q_{ij} + kE * \sqrt{\frac{1}{12}Q_{ij}^2 + VarE_{ij}} \tag{13}$$

$$VarE_{ij} = (l_j)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2 \tag{14}$$

$$SSE_{i,J} = -\frac{1}{2}Q_{i,J} + kE * \sqrt{\frac{1}{12} * Q_{i,J}^2 + VarE_{iJ}} \tag{15}$$

$$VarE_{iJ} = \sum_{j=1}^{J-1}\left[(L_i - R_{ij}) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{(l_j)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2 \tag{16}$$

$$kE = F^{-1}(\alpha) \tag{17}$$

$$k = F^{-1}(\alpha - eP) \tag{18}$$

With:

- $\widehat{kE}$ = Target service factor without the impact of the allowed emergency shipments
- kE = Target service factor with the impact of the allowed lateral shipments based on $\widehat{kE}$
- eP = Emergency percentage

D. Summarizing service factor

The service factor for the regular safety stock is reduced with the emergency percentage and the emergency safety stock uses the total target service level. The impact on the total average inventory is terms of cycle stock is zero since demand during lead time is always less or equal to the demand during lead time and review period. The impact based on safety stock is a bit more challenging since $kE \geq k$ and $\sqrt{l} \leq \sqrt{l+R}$. Therefore the highest safety stock value between SS and SSE is selected, resulting in the following earlier mentioned average inventory calculation:

$$\bar{I}_{ij} = \max\left(SS_{ij}, SSE_{ij}\right) + \frac{\mu_{ij} * R_{ij}}{2} \tag{19}$$

Combining all adjustments on the safety factor results in the following calculations for the safety factor and emergency safety factor required for calculating the safety stock and emergency safety stock:

$$k = \begin{cases} \dfrac{\hat{k}}{\sum_{j=1}^{N} \sqrt{\delta_j}} & if\ lat_{ij} \\ \hat{k} & otherwise \end{cases} \tag{20}$$

$$\hat{k} = \begin{cases} (\alpha' - eP_{ij} - 0.5) * \sqrt{12} & if\ \frac{1}{12} Q_{i,j}^2 \geq 4 * Var_{ij} \\ F^{-1}(\alpha' - eP_{ij}) & otherwise \end{cases} \tag{21}$$

$$\alpha' = \begin{cases} \dfrac{2 * R_{i,J} * \alpha + R_{ij}}{2 * R_{i,J} + R_{ij}} & if\ indirect\ delivery \\ \alpha & if\ direct\ delivery \end{cases} \tag{22}$$

$$kE = \begin{cases} \dfrac{\widehat{kE}}{\sum_{j=1}^{N} \sqrt{\delta_j}} & if\ lat_{ij} \\ \widehat{kE} & otherwise \end{cases} \tag{23}$$

$$\widehat{kE} = \begin{cases} (\alpha' - 0.5) * \sqrt{12} & if\ \frac{1}{12} Q_{i,j}^2 \geq 4 * VarE_{ij} \\ F^{-1}(\alpha') & otherwise \end{cases} \tag{24}$$

With,

- k = Target service factor with the impact of the allowed lateral and emergency shipments
- $\hat{k}$ = Target service factor without allowed lateral shipments, with allowed emergency shipments
- N = Number of warehouses
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N} \mu_x}$ = Percentage of demand satisfied from warehouse i
- α' = Updated service level for different review period at CDC and LDC
  - eP = Emergency percentage
  - α = The required overall service level
  - kE = Target service factor with the impact of the allowed lateral shipments based on $\widehat{kE}$, without impact of allowed emergency shipments
  - $\widehat{kE}$ = Target service factor without the impact of the allowed emergency shipments, without impact of allowed emergency shipments
  - lat_{ij} = True if lateral shipment are allowed

7.1.2 Transportation costs

The transportation costs consist of the sea freight, road transportation and emergency costs. The sea freight costs are the costs for transportation from China to the DC's in Europe, the road transportation costs are the costs for shipping items between DC's and the emergency costs are the cost for emergency transportation from China to the DC's in Europe. Swenseth & Godfrey (2002) assume transportation costs only dependent on shipment size. Since this is in line with this research X and Y have been defined as the shipment size of a container and truck respectively. This resulted in the following calculations for transportation costs:

$$TC_j = SF_j + RT_j + TCE_j \tag{25}$$

$$SF_j = \sum_{p=1}^{P} \sum_{x=1}^{X} containers_{pjx} * TCC_{pjx} \tag{26}$$

$$RT_j = \sum_{w=1}^{J} \sum_{y=1}^{Y} trucks_{wjy} * TCT_{wjy} \tag{27}$$

$$TCE_j = containersE_j * \left(TCCE_j - TCC_{pj3}\right) \tag{28}$$

With:

- $SF_j =$ Annual sea freight costs to warehouse j
- $RT_j =$ Annual road transportation costs to warehouse j
- $TCE_j =$ Annual transportation costs emergency shipment to warehouse j
- $P =$ Number of discharge ports
- $X =$ Number of different container sizes
- $containers_{pjx} =$ Number of containers shipped from port p to warehouse j of size x
- $TCC_{pjx} =$ Costs of shipping one container of size x from port p to warehouse j
- $Y =$ Number of different truck sizes, being the number of pallets fitting in a truck.
- $trucks_{wjy} =$ Number of trucks shipped from warehouse w to warehouse j with y pallets
- $TCT_{wjy} =$ Cost of shipping y pallets from warehouse w to warehouse j
- $containersE_j =$ Containers shipped to warehouse j
- $TCCE_j =$ Transportation costs per container to warehouse j

In the following sub-sections the calculations of the number of containers, trucks and emergency containers shipped per year will be discussed.

A. Containers

The number of containers shipped from port p to warehouse j of shipment size x ($containers_{pjx}$) has been calculated by determining the average number of pallets per shipment from port p to warehouse j ($pallets_{pj}$), this was fitted into the smallest possible number of containers and multiplied with the shipments per year. In doing so it is assumed that sending 2 containers of a smaller size is always more expensive than one container of a larger shipment size. This resulted in the following calculation:

$$containers_{pjx} = \left\lceil \frac{pallets_{pjx}}{PpC_x} \right\rceil * \frac{52}{baseR} \quad (29)$$

$$pallets_{pjx} = \left(pallets_{pj} - \sum_{x2=x+1}^{X} \left\lceil \frac{pallets_{pjx2}}{PpC_{x2}} \right\rceil * PpC_{x2} - PpC_{x-1} \right) \quad (30)$$

$$pallets_{pj} = \sum_{i \in I^{pj}} \frac{\mu_{ij}}{PalUn_i} * baseR \quad (31)$$

$$\{I^{pj} \subseteq I \middle| port_i = p \ \cap \left(ItemFlow_{ij} = 0 \cup j = J \right) \} \quad (32)$$

With:

- $pallets_{pjx}$ = Pallets shipped per review period from port p to warehouse j in a container of size x. (note the roundup brackets)
- $baseR$ = Base review period (4 weeks)
- PpC_x = Pallets per Container of size x
- $pallets_{pj}$ = Total number of pallets shipped per week from port p to warehouse j
- $port_i$ = Port of discharge of item i
- $ItemFlow_{ij}$ = Flow of item i to warehouse j with 0 and 1 for a direct and indirect delivery respectively

For example: Assuming a 4 week review period, 100 pallets shipped from port p to warehouse j via a direct flow and 30, 60 and 70 pallets per container of size 20 FT, 40 FT and 40FT HC respectively. Gives the calculations below, resulting in 26 containers shipped per year from port p to warehouse j. With 13 20FT containers and 13 40FTHC containers.

$$pallets_{pj} = 100 \qquad X = 3$$

$$PpC_x = 30, 60 \ and \ 70 \ for \ x = 1, 2 \ and \ 3 \ for \ 20 \ FT, 40 \ FT \ and \ 40 \ FT \ HC \ respectively$$

For the largest container size this gives the following:

$$pallets_{pj3} = (100 - 0 - 60) = 40$$

$$pallets_{pj2} = \left(100 - \left\lceil \frac{40}{70} \right\rceil * 70 - 30 \right) = (100 - 1 * 70 - 30) = 0$$

$$pallets_{pj1} = \left(100 - \left(\left\lceil \frac{0}{60} \right\rceil * 60 + \left\lceil \frac{40}{70} \right\rceil * 70 \right) - 0 \right) = (100 - (0 + 70) - 0) = 60$$

$$containers_{pj3} = \left\lceil \frac{pallets_{pjx}}{PpC_x} \right\rceil * \frac{52}{baseR} = \left\lceil \frac{70}{70} \right\rceil * \frac{52}{4} = 13$$

$$containers_{pj2} = \left\lceil \frac{0}{60} \right\rceil * \frac{52}{4} = 0$$

$$containers_{pj1} = \left\lceil \frac{30}{30} \right\rceil * \frac{52}{4} = 13$$

B. Trucks

The number of trucks shipped from warehouse w to warehouse j with y pallets per truck ($trucks_{wjy}$) has been calculated by determining the average number of pallets shipped from warehouse w to warehouse j ($pallets_{wj}$), then this was fitted into the smallest possible number of trucks. In doing so it is assumed that sending 2 trucks of a smaller size is always more expensive than sending one truck of a larger size. This resulted in the following truck calculation:

$$trucks_{wjy} = \left\lceil \frac{pallets_{wjy}}{PpT_y} \right\rceil * 52 \tag{33}$$

$$pallets_{wjy} = pallets_{wj} - \sum_{y2=y+1}^{Y} \left\lceil \frac{pallets_{wjy2}}{PpT_{y2}} \right\rceil * PpT_{y2} - PpT_{y-1} \tag{34}$$

The number of pallets shipped from the CDC to the LDC depend on the flow of the different items (direct or indirect). The number of pallets shipped between the different LDC's depend on the allowed lateral shipments. When no lateral shipments are allowed the pallets shipped between LDC's are zero.

The pallets shipped from the CDC to the LDC are calculated in a similar way as the pallets shipped from port to warehouse. This means that the pallets shipped is the sum of the demand for all items with an indirect flow is divided by the number of items.

$$pallets_{wj} = \sum_{i=1}^{I} \frac{\mu_{ij}}{PalUn_i} [ItemFlow_{ij} = 1] \qquad if\ w = J \cap w \neq j \tag{35}$$

The pallets shipped between LDC's, i.e. the lateral shipments are determined based on the calculations provided by Naseraldin and Herer (2011, p. 444). They described a calculation for the total costs including the lateral transshipments. In this calculation the transshipment costs are included as separate factor. The transshipment calculation is:

$$T_{ij} * \sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N} \sqrt{\delta_j}}\right) \sum_{j=1}^{N} \sqrt{\delta_j} \tag{36}$$

T_{ij} is defined as the lateral transshipment costs to warehouse j. Therefore the rest of the formula is the transshipment quantity to warehouse j. However the costs of lateral transshipments do not depend on the shipment size alone. They also depend on the warehouse shipping the items due to different distances between warehouses. Therefore a preferred supplier or best source (BS) is selected for each item based on the method described by Lau et al. (2016). This method selects a preferred supplier based on the minimal costs. However not all items are on stock at all warehouses, therefore another restriction is that in order to allow lateral shipments both warehouses must have demand and therefore inventory for that item. This calculation can be seen in equation (38). The transshipment quantity is used to determine the expected number of pallets shipped between the different local warehouses. This results in the following calculation for $pallets_{wj}$ for lateral shipments:

$$pallets_{wj} = \sum_{i \in BS_{wj}} \frac{\sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N} \sqrt{\delta_j}}\right) \sum_{j=1}^{N} \sqrt{\delta_j}}{PalUn_i} \tag{37}$$

$$\{BS_{wj} \subseteq I \,|\, \mu_{ij} > 0 \cap lat_{ij} \cap pref_{iwj} \cap w \neq J \cap j \neq J\} \tag{38}$$

$$pref_{iwj} = \begin{cases} true & if\ TCT_{wj1} = \min\left(TCT_{:j1} | (\mu_{iw} > 0)\right) \\ false & otherwise \end{cases} \tag{39}$$

With:

- BS_{wj} = Set of all items at warehouse j that have warehouse w as best source for lateral shipments
- lat_{ij} = True if lateral flow allowed for item i at warehouse j
- $pref_{iwj}$ = True if warehouse w is the preferred supplier of item i to warehouse j
- $\min\left(TCT_{:j1}|(\mu_{iw} > 0)\right)$ = The warehouse w with the lowest transshipment costs to warehouse j that has demand for item i

Combining all these calculations results in the following formulas for the expected number of pallets shipped from the CDC to the LDC's and between the LDC's:

$$pallets_{wj} = \begin{cases} \sum_{i=1}^{I} \frac{\mu_{ij}}{PalUn_i}\left[ItemFlow_{ij} = 1\right] & if\ w = J \cap w \neq j \\ \sum_{i \in BS_{wj}} \frac{\sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}}\right)\sum_{j=1}^{N}\sqrt{\delta_j}}{PalUn_i} & otherwise \end{cases} \tag{40}$$

With:

- $pallets_{wjy}$ = Pallets shipped per week from warehouse w to warehouse j in a truck with y pallets.
- PpT_y = Pallets per Truck of size y
- $pallets_{wj}$ = Total number of pallets shipped per week from warehouse w to warehouse j
- $\hat{k}$ = Target service factor with the impact of the allowed emergency shipments based on α'
- k = Target service factor with the impact of the allowed lateral shipments based on $\hat{k}$
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N}\mu_x}$ = Percentage of demand satisfied from warehouse i
- BS_{wj} = Set of all items at warehouse j that have warehouse w as best source for lateral shipments

C. Emergency containers

The number of emergency containers shipped to each warehouse is determined by first determining the number of pallets shipped to each warehouse, which is calculated by multiplying the emergency percentage with the demand and summing this over all items. This is used to calculate the expected number of containers, as done in the container calculation. However only 40 FT HC containers are considered since there is no price difference in shipping 20, 40 and 40 FT HC containers via rail transportation. Another difference between the sea freight calculations is that the costs and lead times are equal for all ports of discharge. Therefore the port of discharge can be ignored. This results in the following calculation:

$$containersE_j = \left\lceil \frac{\sum_{i \in I^j} \frac{\mu_{ij} * eP_{ij}}{PalUn_i} * baseR}{PpC_3} \right\rceil * \frac{52}{baseR} \tag{41}$$

$$I^j \subseteq I|\left(ItemFlow_{ij} = 0 \cup j = J\right) \tag{42}$$

7.1.3 Inbound costs

The inbound costs have been calculated for each warehouse individually to allow lateral shipments which influence the inbound (and outbound) costs per warehouse, this impact will be described in section I.2. These costs will be calculated for the incoming trucks and containers separately allowing lateral shipments will increase the number of trucks, the number of containers will remain the same. This resulted in the following calculations:

$$IBC_j = \sum_{x=1}^{X} \left[\sum_{p=1}^{P} containers_{pjx} \right] * inboundCostPerContainer_{jx} + \sum_{y=1}^{Y} \left[\sum_{w=1}^{J} trucks_{wjy} \right] * inboundCostPerTruck_{jy} \quad (43)$$

$$inboundCostPerContainer_{jx} = PpC_x * InboundCostPerPallet_j \quad (44)$$

$$inboundCostPerTruck_{jy} = PpT_y * InboundCostPerPallet_j \quad (45)$$

7.1.4 Outbound costs

The outbound costs have been calculated for each warehouse individually since, as mentioned before, lateral shipments will be investigated which influence the outbound costs per warehouse. This will be discussed in section I.2. These costs will be calculated for the outgoing trucks, allowing lateral shipments will increase the number of trucks, resulting in the following calculations:

$$OBC_j = \sum_{y=1}^{Y} \left[\sum_{w=1}^{J} trucks_{jwy} \right] * OutboundCostPerTruck_{jy} \quad (46)$$

$$outboundCostPerTruck_{jy} = PpT_y * OutboundCostPerPallet_j \quad (47)$$

7.2 Flow decision

In order to choose between different setups a total cost function has been used to calculate the expected costs of each setup. This total cost function uses the total cost function developed by Thomas Wijnberg as starting point. However not all assumptions were exactly the same, therefore these calculations have been adapted to fit the assumptions and goals of this research. The assumptions made by Wijnberg that are in line with this research are:

1. Normally distributed demand
2. Equal inventory policy over all warehouses but different demand
3. Demand for consecutive periods and demand for different locations and products are stochastic and independent
4. Average demand is equal for each month of the year, no distinctions are observed
5. All demand that cannot be satisfied directly from stock is backordered
6. Demand is stationary on the daily level per month
7. There are no constraints regarding storage capacities
8. Products are non-perishable
9. Product values are constant

The assumptions that were not exactly the same were:

1. Suppliers always deliver orders immediately after production and production time is never exceeded
2. Transshipments between local stock points are not allowed
3. All lead times are constant and deterministic. Therefore they have no influence on inventory levels via extra safety stock

Additionally Wijnberg took the possibility of switching between Chinese and European sourcing into account which is out of scope for this research and Wijnberg did not take emergency shipments into account. In Appendix II the calculations provided by Wijnberg are evaluated. Wijnberg's method however gives the opportunity of local optimization instead of system wide optimization. For example with this method it might be interesting for a certain item to be shipped directly to Grossostheim causing the costs of the total system to rise since the minimal order quantity for the CDC will not be met anymore. See Table 10.1

Table 7.1: Example flow selection with local optimization

Warehouse	Dem	MOQ	Individual Optimal flow	Total optimal flow
A	1000	1000	Direct	Indirect
B	200	1000	Indirect	
C	200	1000	Indirect	

Therefore the method by Wijnberg is updated to a recursive algorithm that determines the best item flow. This algorithm is as follows:

1. Set flow for all items and warehouses with demand>0 to indirect delivery
2. Calculate expected costs
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to direct delivery
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch
5. Repeat step 3 and 4 until all items are delivered to the warehouses via direct delivery
6. Select the best result of step 4 and retrieve the settings corresponding to this result

The expected supply chain costs based on the settings of this method are roughly € 0.5 million below the expected costs when the settings resulting from the original method from Wijnberg would have been used. This shows that looking at the supply chain as a whole instead of per warehouse does indeed have an impact on the expected costs and gives a potential profit.

7.3 Lateral decision

Exactly calculating the optimal setup for lateral shipments is according to Lau et al. (2016), Tagaras & Vlachos (2002) and others, mathematically intractable. Therefore the preferred lateral settings will be determined via the algorithm below.

1. Use lateral shipments for all items and warehouses
2. Calculate expected costs
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to no lateral shipments
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch
5. Repeat step 3 and 4 until no items have lateral shipments
6. Select the best result of step 4 and retrieve the settings corresponding to this result

In order to use this algorithm the calculations described in the previous section have to be updated. Lau et al. (2016) suggested a roadmap for lateral transshipments. This roadmap evaluates in several steps whether a lateral transshipment should occur and, if so, what amount should be shipped, from which warehouse and if there should be an additional transshipment quantity to correct for possible future shortages. Lau et al. (2016) assume periodic review policy. Their logic on selecting a preferred supplier based on the costs is used, however they take backordering costs into account which are not taken into account in this research. So the other steps (amount and additional quantity) cannot be used.

Whether a lateral flow is allowed will be determined via the algorithm described above, which determines the preferred choice for the use of lateral shipments.

7.4 Emergency decision

For the use of emergency shipments several choices have to be made regarding the setup. Unfortunately the acquired literature focused on reactive instead of proactive emergency shipments. Therefore the preferred emergency settings will be determined via the algorithm described below.

1. For each item and warehouse combination calculate total costs for having an emergency percentage between $\frac{1}{1000}$ and α with steps of $\frac{1}{1000}$ and select the percentage with the lowest expected total costs
2. Calculate expected costs based on these percentages
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to no emergency shipments
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch
5. Repeat step 4 and 5 until no items have lateral shipments
6. Select the best result of step 5 and retrieve the settings corresponding to this result

In order to use this algorithm the calculations described in the previous sections have to be updated. Alfredsson & Verrijdt (1999) describe a reactive system with lateral and emergency deliveries. This idea can be used as base for the reactive emergency shipments by determining the percentage that will be satisfied via emergency shipments beforehand and reducing the service level (and safety stock) with that percentage. However it triggers at the same time an emergency shipment of that percentage of the demand. Since this emergency shipment has a non-fixed lead time the order should take this into account. This will be done by introducing an emergency safety stock level. This idea was adopted from the research of Tagaras & Vlachos (2002) who described a method for lateral shipments.

8 Model outcomes

The preferred supply chain setup will be selected based on the results of the calculations and methods described/developed in the previous chapter. In order to make this decision a Matlab model has been developed to compare the expected costs of the different supply chain setups. The Matlab code is given in Appendix IV. Before processing the results the model outcomes have been checked in order to ensure a correct calibration. This calibration is discussed in the first section of this chapter. In the second until fifth section the preferred setup for the CDC, lateral shipments, emergency shipments and review period are discussed and the final section discusses the overall preferred setup.

8.1 Model setup & cost comparison

The model calibration compares the actual costs discussed in chapter 6 with the expected costs resulting from the model. The first step in this calibration process calculates the expected costs based on the actual inventory, containers and trucks. These costs are compared with the actual costs used in the cost summary in Table 6.7 of section 6.1.5. There were some differences in these results, Table 8.1 shows the % difference between the different cost factors and gives a reason for each difference. The main reason for the difference is the exclusion of the out of scope items.

Table 8.1: Reasons cost difference between Actual costs and model costs with fixed input

Cost factor	*% difference*	*Reason difference*
Inventory Interest	- 9%	Out of scope items removed
Inventory Storage costs	-21%	
Sea Transportation costs	0%	-
Inbound costs	-43%	Removal of out of scope and French items
Outbound costs	-43%	
Road Transportation costs	-10%	Out of scope items removed
Total	-12%	Removal of out of scope and French items

After checking the total cost calculations the inventory, container and truck calculations are released to check these for correctness as well. This has been done in two steps.

1. Release inventory, container and truck calculations but maintain current safety stock
2. Use new safety stock calculation based on actual service level, lead time and lead time variance

Table 8.2 shows the percentage difference between these models compared to the model with fixed input parameters for inventory, trucks and containers. These differences are discussed in the following two paragraphs.

The expected total inventory expenses in the step with the current safety stock are over 65% below the model with fixed input. This would result in a service level of roughly 80%, which is way below the target and actual service level of 99 and 98.5% respectively.

The expected total inventory expenses in the step with the new safety stock calculation are 15% lower than in the model with fixed input. This would maintain the current service level. This difference is partially due to unknown CDC data but another part is due to realistic saving potential. Unfortunately it was not possible to make a distinction on a CDC level. The remaining differences are mainly in the road transportation and outbound costs. In outbound costs the difference is 28%, however since this is less than 1% of the total costs this difference is accepted. The differences in the road transportation costs are due to stacking of items, normally a truck has 33 pallet places but in reality cases were seen where 66 pallets were shipped in one truck (2 per pallet place). Data analysis gave that there are on average 1.25 pallets on one pallet place. Therefore the total number of pallets is divided by 1.25 to correct for this difference. Unfortunately a better cost approach could not be made on this cost factor forcing the acceptance of this approach (assuming that the other cost differences are due to human intervention).

Table 8.2: Percentage cost difference in cost calibration

	Fixed safety stock	*New Safety stock*
Inventory Interest	-65%	-15%
Inventory Storage costs	-71%	-12%
Sea Transportation costs	-1%	-1%
Inbound costs	4%	4%
Outbound costs	28%	28%
Road Transportation costs	36%	36%
Total	-24%	-2%

To give an overview of the cost factors compared to one another Figure 8.1 shows the costs for each step. This shows that most costs can be allocated to transportation which is supported in literature for example by Swenseth & Godfrey (2002) who claim that over fifty percent of the total logistics costs can be assigned to transportation.

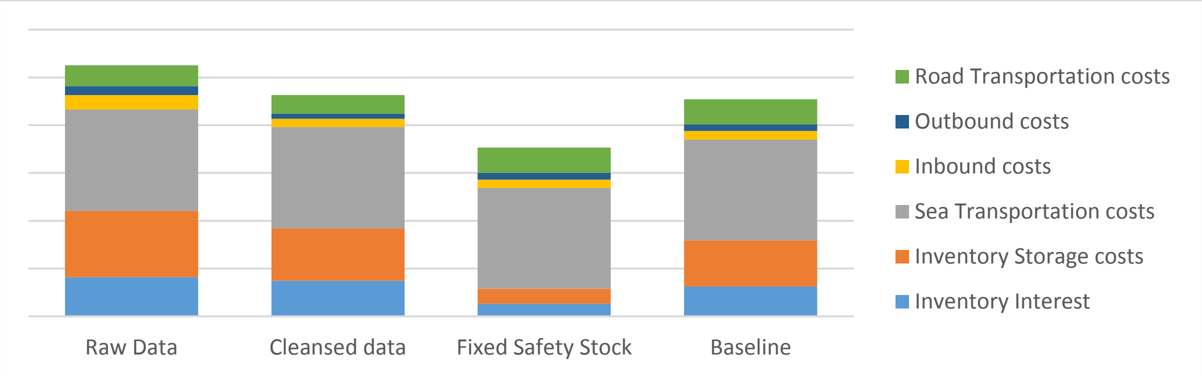


Figure 8.1: Model Calibration

8.2 CDC

In order to select the preferred item flow (direct vs indirect) and warehouse location (Zwolle vs China) the calibrated baseline defined in the previous paragraph has been compared with several alternative setups. These were:

1. No CDC flow
2. Full CDC flow
3. CDC flow for select number of items (based on algorithm described in paragraph 7.2)

This resulted in the expected costs shown in Figure 8.2 which shows that having no CDC gives a small improvement compared to the current setup with 2% expected savings. Sending all items via the CDC is not interesting since the expected costs are 21% higher than the current setup. Shipping a select number of items (20%) via the CDC based on the algorithm defined in paragraph 7.2 gives the lowest expected costs with an expected cost improvement of 10%.

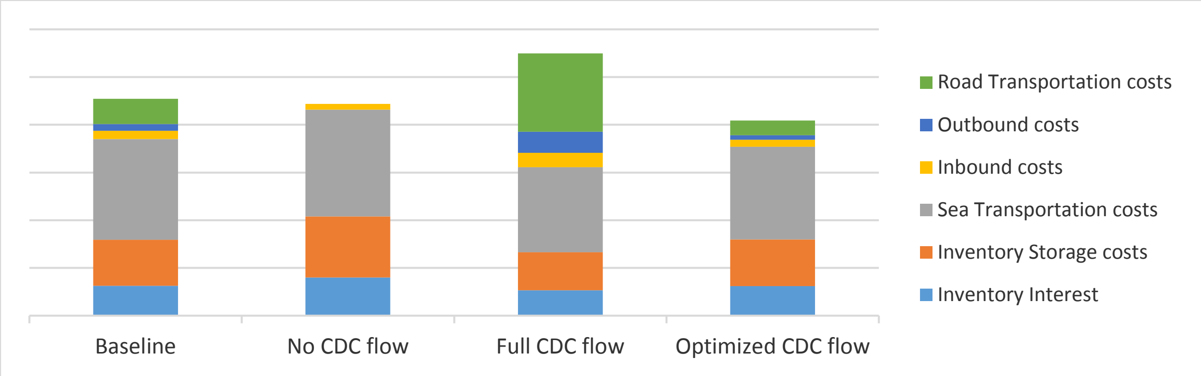


Figure 8.2: CDC selection

Another option would be to locate the CDC in China. In order to evaluate this option several assumptions were required since there is little information known about the corresponding costs.

1. The indirect flow uses a 4 week review period (as done in the direct flow). This is needed to fill up a container. In reality partial containers could be shipped which would allow using a weekly review period, however these rates are unknown.
2. Cost of storage space and handling in China are unknown and therefore assumed equal to the current CDC storage and handling costs.
3. The lead time variance between the CDC and LDC's is a result of the combined performance of the CDC and the carrier. Since it is unknown what part of the lead time variance is due to the CDC service level two assumptions are checked.
    a. Lead time variance between CDC and LDC is not dependent on the CDC service level (optimistic)
    b. Lead time variance between CDC and LDC is completely dependent on the CDC service level (pessimistic)

In order to take the optimistic and pessimistic assumptions into account the expected costs have been calculated twice, in these calculations the following setup was used:

- Optimistic: Lead time variance CDC China equals the current lead time variance from vendor to warehouse.
- Pessimistic: Lead time variance CDC China equals the current lead time variance from vendor to warehouse plus the current lead time variance between the CDC and LDC's.

The expected costs for the optimal CDC usage with a CDC in Zwolle and China can be seen in Figure 8.3. The first column is equal to the last column in Figure 8.2, the second and third column show the best and worst case expected costs respectively. The difference between the optimistic and pessimistic assumption for lead time variance between CDC and LDC is less than 1%. Switching to a CDC in China does give an expected saving of 6% compared to the CDC in Zwolle with reviewed item flow. When the item flow would not be reviewed the cost reduction would only be 2%.

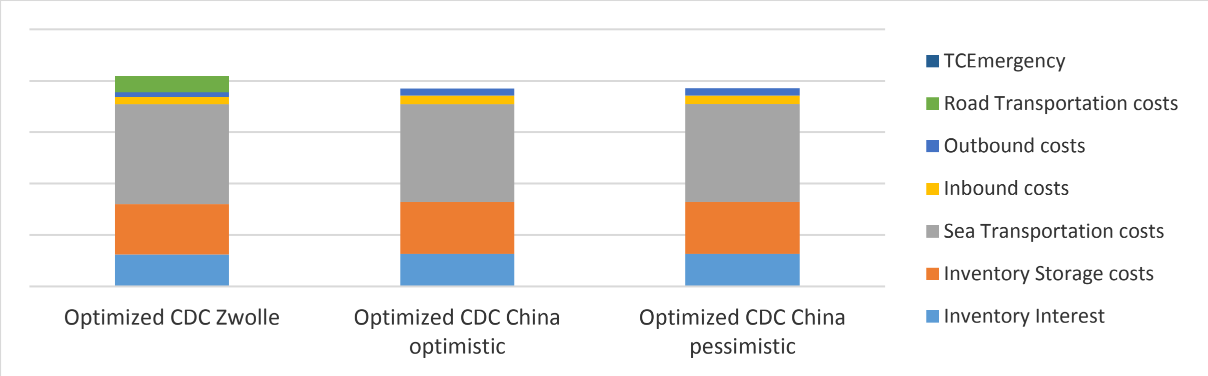


Figure 8.3: CDC Zwolle VS China

Advantages CDC China

- Looking at the total costs in more detail shows that placing the CDC in China yields lower inventory values in the CDC but higher inventory values at the LDC's. This makes sense since the lead time towards the CDC is reduced and the lead time between the CDC and the LDC's is increased.
- Overall a small stock increase is observed, but the decrease in transportation costs is higher.
- Additionally the cost differences at the different local warehouses have been compared in Appendix III, Figure 10.2. This showed that switching to China reduces the LDC costs for most warehouses.

Disadvantages CDC China

- In transit costs can no longer be ignored, since the items will be property of Office Depot upon arrival at the CDC instead of arrival at the port in Europe. In the preferred setup this would roughly yield a 2% cost increase (based on average lead time).
- Additionally some assumptions were required due to lack of data availability:
    - Same holding and handling costs per pallet as in original setup
    - No additional transportation costs in China
    - Available space in original CDC warehouse can be used for other purposes (opportunity costs)
- Impact on the items of European vendors that are ordered via the CDC should be taken into account since these need to be switched to direct delivery.

The above analysis shows that using the CDC for a select number of items is a wise decision. However the entire company should be taken into account while deciding which items to ship direct and indirect. Otherwise a system without a CDC should be used. Additionally the model shows a preference for the usage of a CDC in China. However in these calculations several assumption were made which have to be checked for correctness before actually switching to China. Therefore, for now, a setup with a CDC in Europe should be used. In this setup the system wide decision making needs to be implemented anyway. When this shows actual results and the additional information on a CDC in China is known switching can be done quite easily.

8.3 Lateral shipments

The preferred number of lateral shipments has been calculated according to the method described in paragraph 7.3. First a system without a CDC is tested, since this setup has the highest possibility of allowing lateral shipments. This setup can be seen in Figure 8.4.

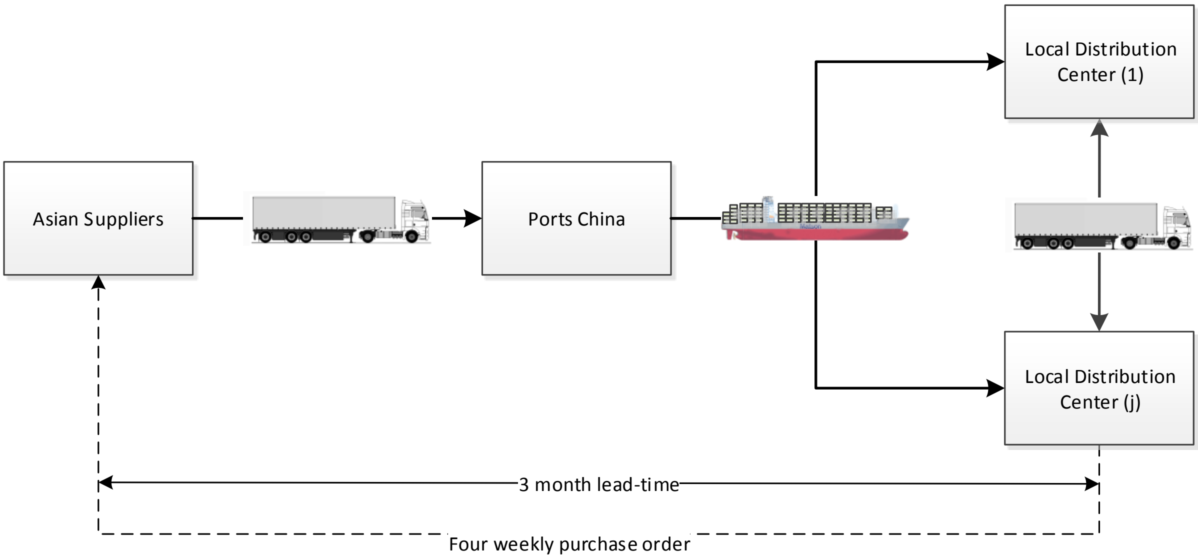


Figure 8.4: Initial supply chain setup lateral shipments

In this calculation the lateral transshipment costs per pallet were required. Figure 8.5 shows the cost per pallet dependent on the number of pallets per shipment for shipments from the CDC to the LDC's. The rates between the different flows are only known while assuming one pallet per shipment (most expensive option). To ensure that this does not influence the eventual decision the expected costs have been calculated twice.

- Assuming one pallet per shipment based on 100% of the costs provided by the carrier
- Assuming >10 pallets per shipment based on 50% of the costs provided by the carrier

The second assumption makes sense when looking to the cost development as shown in Figure 8.5 however when lateral shipments are used it should be checked whether the shipped volume is sufficient.

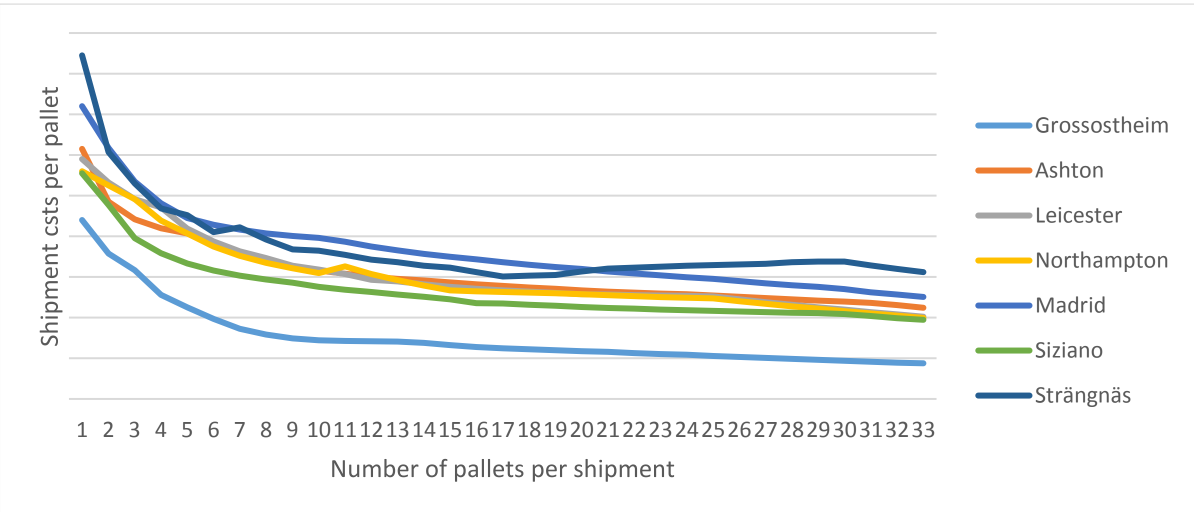


Figure 8.5: Costs per pallet dependent on the number of pallets per shipment

This resulted in the expected costs of a system with lateral shipments allowed for a decreasing number of items. The cost development with full and 50% costs can be seen in Figure 8.6 where the decreasing number of items with lateral shipments are depicted on the x-axis and the expected costs on the y-axis. This shows that lateral shipments should not be used for both lateral shipment cost assumptions.

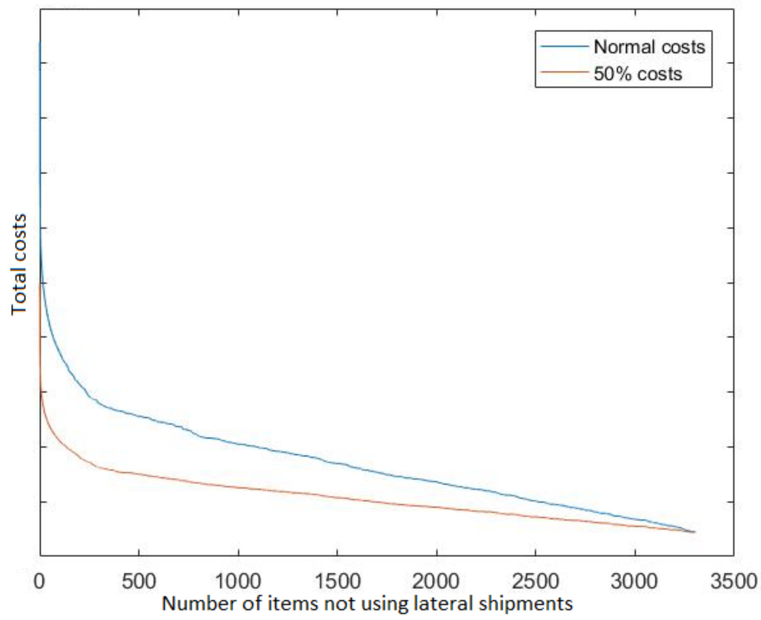


Figure 8.6: Cost development for decreasing usage of lateral shipments

8.4 Emergency shipments

The preferred number of emergency shipments has been calculated according to the method described in paragraph 7.4. First a system without a CDC is tested, since this setup has the highest possibility of allowing emergency shipments. For emergency shipments two emergency flows have been evaluated, being emergency shipments via rail and air. The setup and the average lead time reduction per selected emergency flow can be seen in Figure 8.7.

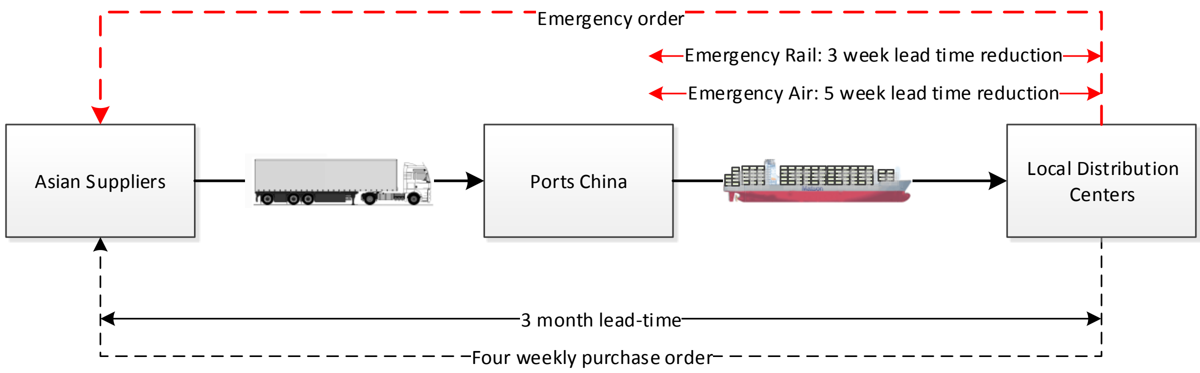


Figure 8.7: Initial setup emergency shipments

This resulted in the expected costs of a system with emergency shipments allowed for a decreasing number of items. The results in Figure 8.8 show that systematic emergency shipments only yield minor cost savings (1% for rail and 3% for air). Air transportation seems most interesting. However evaluating this for a system with a CDC gives no cost savings, resulting in the same costs as described in section 8.2. Therefore using emergency shipments via rail or air on a regular basis is not preferred.

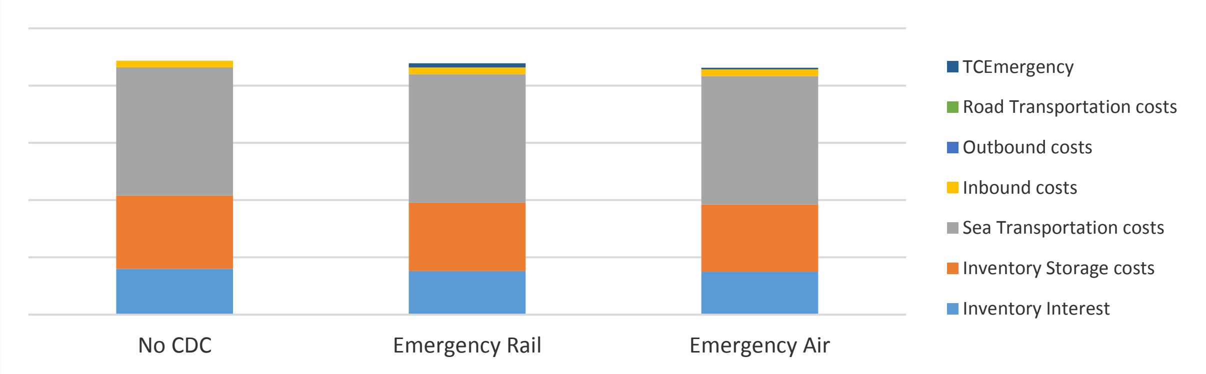


Figure 8.8: Expected costs with emergency rail and air shipments

8.5 Review period

In the previous calculations a 4 week review period has been used. Changing this review period might influence the results and conclusions. Therefore the expected costs of a two and six week review period have been calculated as well. The results shown in Figure 8.9 show that using a four week review period is preferred.

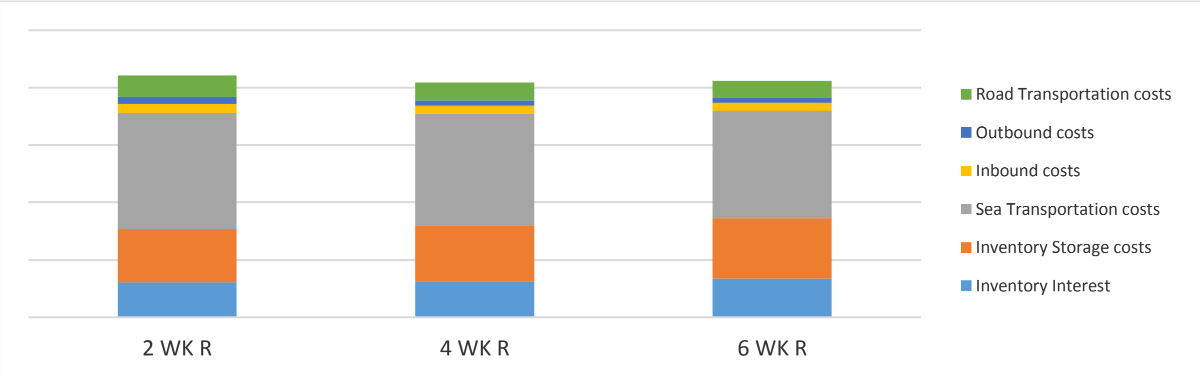


Figure 8.9: Expected costs per warehouse with 2, 4 and 6 week review period

Additionally the expected costs of a single echelon system with a variable review period (without lateral and emergency shipments) have been calculated. The results shown in Figure 8.10 show that a review period of 4 or 5 weeks would yield the lowest costs. This was compared with the preferred CDC flow, which shows that the 4 week review period remains the preferred review period. Additionally a four week review period is better implementable since this yields 13 order moments per year instead of the 10.4 when a 5 week review period would be maintained. Therefore a 4 week review period should be maintained.

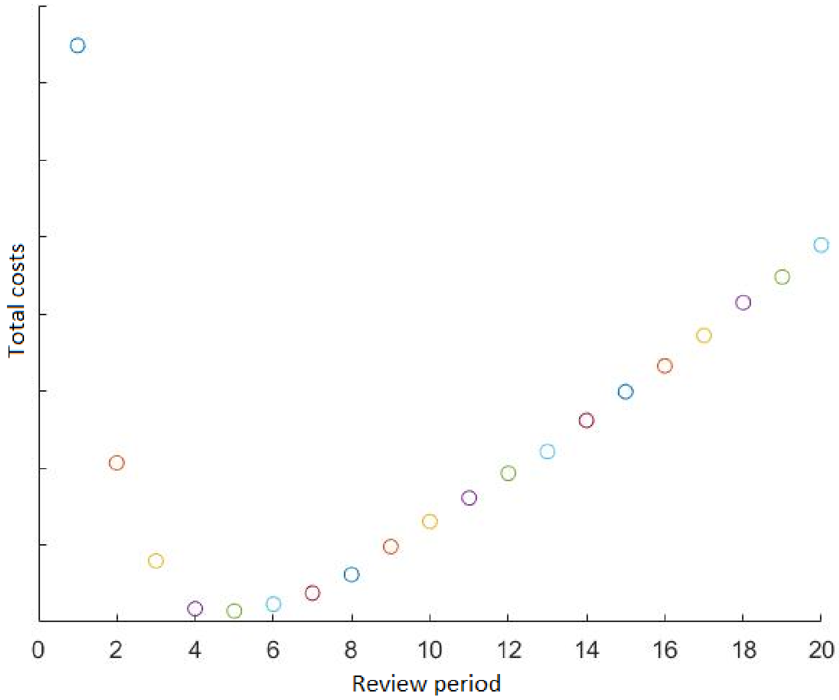


Figure 8.10: Expected cost vs review period

8.6 Answering sub questions

Based on the results in the previous sections the sub questions related to this chapter have been answered which gave a preferred supply chain setup consisting of two echelons, with a CDC in China, sea freight transportation and a 4 week review period. In the calculations of the total costs for a CDC in China however there were several uncertainties, therefore the (more certain) setup with a CDC in Zwolle has been selected. Improving the item flow will yield up to 10% savings based on the expected total costs. With the new safety stock calculation for the CDC a target service level can be selected. Increasing the service level will probably lead to a lower lead time and lead time variance for the indirect flow. The reorder level should be calculated via the formulas given below with the safety stock calculations given before (in formulas (4) and (6)). Since emergency and lateral shipments are not part of the preferred supply chain setup, the calculations for the average inventory and service factor have been updated, see formula (50) and (51).

$$s_{ij} = (l_j + R_{ij}) * \mu_{ij} + SS_{ij} \qquad for\ \forall\, j < J \tag{48}$$

$$s_{iJ} = \sum_{j=1}^{J} (L_i + l_j + R_{ij}) * \mu_{ij} + SS_{iJ} \tag{49}$$

$$\bar{I}_{ij} = SS_{ij} + \frac{\mu_{ij} * R_{ij}}{2} \tag{50}$$

$$k = \begin{cases} (\alpha' - 0.5) * \sqrt{12} & if\ \frac{1}{12} Q_{i,j}^2 \geq 4 * Var_{ij} \\ F^{-1}(\alpha') & otherwise \end{cases} \tag{51}$$

The cost differences between the current and preferred setup can be seen in Figure 8.2. This shows that improving the item flow selection could yield a total cost saving of 10%. Comparing the costs of the current and preferred setup in more detail shows that the new setup would decrease costs at 7 out of 9 warehouses (Figure 8.11). Additionally the inbound, outbound and transportation costs are reduced. The inventory expenses compared to the baseline remain the same (Figure 8.12).

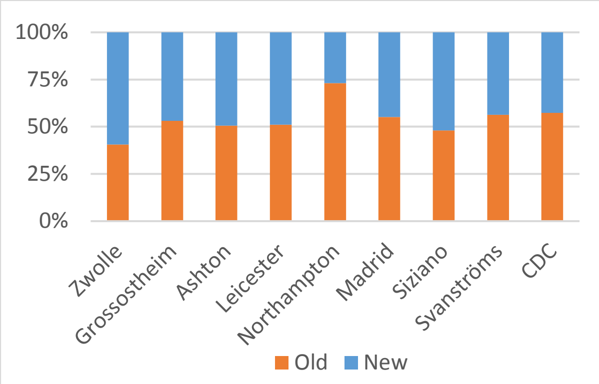


Figure 8.11: Cost comparison old vs new setup per warehouse

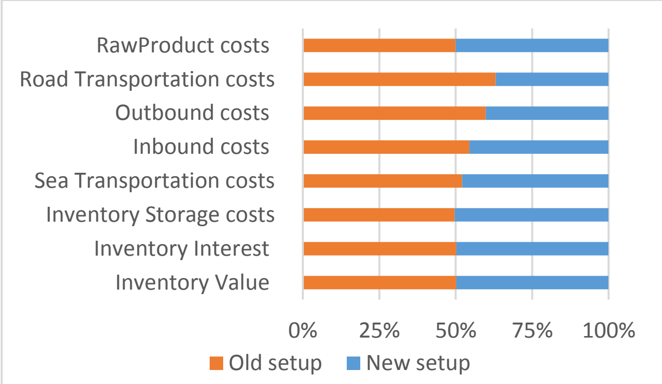


Figure 8.12: Cost comparison old vs new setup per cost factor

Despite the fact that the total inventory expenses are equal for both setups, Figure 8.13 shows that inventory expenses per warehouse do change. This explains why other item flow decisions do impact transportation costs, etc., but not the overall inventory expenses. Furthermore inventory savings can be made when comparing the model with the actual situation since a new safety stock calculation has been introduced that could yield up to 15% inventory value reduction. It should be taken into account that part of this reduction is due to out of scope items. Unfortunately it is not possible for the CDC to make a distinction between the impact of the new safety stock calculation and the impact of the removal of out of scope items. It is known that 5% of this reduction is realizable in the LDC's.

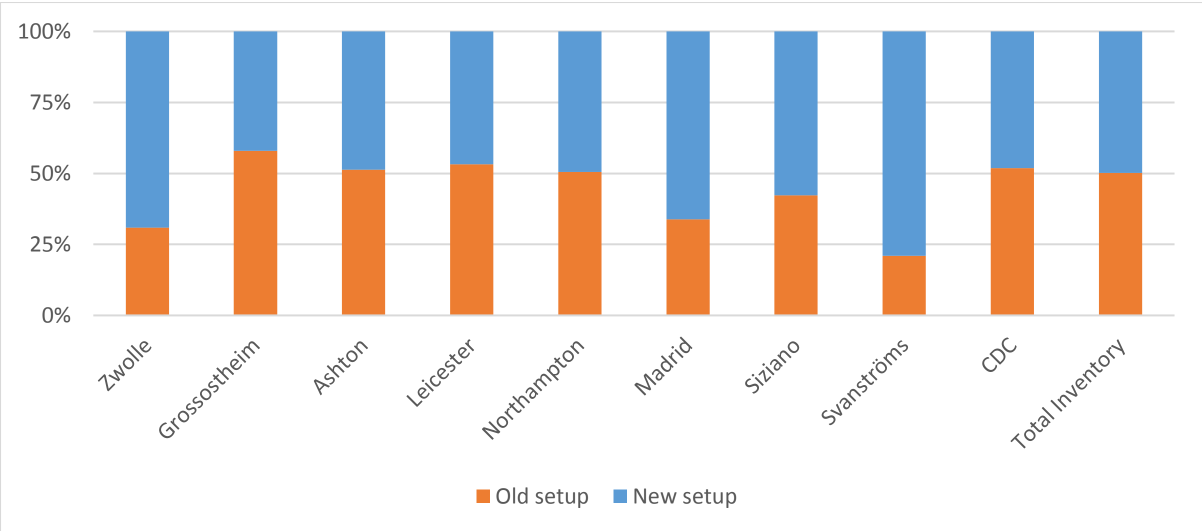


Figure 8.13: Inventory expenses per warehouse

9 Results and conclusion

This chapter presents the main findings of the research and answers the main research question. Additionally the limitations of this research are discussed followed by some recommendations and possibilities for future research for Office Depot.

The project started with a management dilemma. Based on which a main research question has been developed to assist in solving the management dilemma. The management dilemma and main research question were:

Management dilemma: *The supply chain cost and on hand inventory value of the private label products sourced in Asia is too high.*

Main research question: *How should the supply chain of products sourced in Asia be setup in order to minimize supply chain cost and on hand inventory value while maintaining the current product availability level?*

Based on the research several changes in the supply chain setup should be made. Other parts of the current supply chain setup should remain the same. Therefore the different parts of the supply chain setups will be discussed.

- The number of echelons should remain at 2 for a select number of items. Compared to the current setup the % of items following a direct flow should be reduced from 26 to 20%. At this moment most savings (up to 10%) can be made by reevaluating for each item whether it should follow a direct or indirect flow since the model indicated that 20% of the items should switch from direct to indirect or vice versa.
- In the long term it should be considered to relocate the Central Distribution Center to China, however some additional information should be gathered before making this decision (see future research). Additionally the impact on the items of European vendors that are ordered via the CDC should be taken into account since these need to be switched to direct delivery.
- The current transportation method, sea freight, should be maintained. Using emergency or lateral shipments for a fixed percentage of demand is not interesting, however when extremely unexpected demand occurs they could be used to cover the gap (accepting higher costs).
- The current safety stock calculations should be reevaluated, especially for the Central Distribution Center since at this moment there is no calculation behind the safety stock value. This could give up to 15% inventory value reduction. Office Depot could also choose to improve the service level of the Central Distribution Center, which would theoretically yield lower safety stock at the Local Distribution Centers and possibly making the usage of the CDC interesting for more warehouses.
- Changing the review period is not recommended since this would increase the total costs. Switching to a two week review period does reduce inventory value and expenses, however the transportation costs increase more. Switching to a six week review period does reduce the transportation costs, however the inventory expenses increase more.
- The reorder level calculations are fine, as long as the safety stock calculations are improved.
- The current forecast method has not been evaluated extensively since the forecasting method was too vague to give good comments on. Additionally Office Depot is evaluating this performance internally. When the forecast performance is improved this should be taken into account in the safety stock calculations since a better forecasting performance yields a lower safety stock.

9.1 Limitations

This research has some limitation due to assumptions and time constraints these are discussed below:

1. The in transit costs were excluded due to vendor agreements, however when switching to a CDC in China these costs would become relevant. It could be argued that these costs are somehow included in the item price at this moment. Therefore the item price or minima's agreed with the vendor could be reduced when delivery in China is requested instead of EU delivery.
2. No data available on the handling and storage costs of a CDC in China, therefore some assumptions were made for these handling and storage costs.
3. Transportation costs are calculated based on the expected number of pallets per container and truck. Corrections were made for the fill rate of a container and the stacking of pallets in trucks, however this is not an exact approach.
4. Some items and warehouses were out of scope, therefore not all costs have been taken into account. Taking these items into account would change the total costs. However it is expected that the overall conclusion remains the same.

9.2 Recommendations

Based on the analysis performed during this project several possible improvements came forward. Therefore several recommendations for Office Depot to improve their overall performance are:

1. The CDC forecast is made per warehouse, however a major strength of a CDC is variability pooling which is obtained by making a forecast on the total demand instead of the individual demands.
2. The safety stock in the CDC should be based on demand variation instead of a fixed number of days selected based on trial and error without taking variance into account.
3. The decision to select either a direct or indirect flow should be made while taking the overall costs into account, i.e. instead of evaluating whether a local warehouse has sufficient demand to send directly it should also be evaluated whether the other warehouses can miss the demand of that warehouse in their central order.
4. The vendor agreements should be evaluated since for some items the minima's agreed with the vendors are bigger than one year of demand. Causing unnecessary high inventory. If the vendor constraints would be completely removed a cost reduction of up to 8% could be achieved, regardless the selected setup. In addition to this vendor lead times should be included in the contracts since right now the vendors give an estimate of the lead time at the moment the order is placed based on which there performance is measured. This gives the suppliers the opportunity to change its lead time each order.
5. In planning the actual vendor lead time should be used instead of the (at this moment non-contractual) agreed lead time since otherwise orders might be placed too late or early due to changes in the actual lead time causing over- or understocking.

9.3 Future research

During this project several possibilities for future research were discovered. These will be discussed below:

1. This project had a wide scope to check and improve the current overall supply chain setup. Therefore it was not possible to gather all information on a CDC in China. In future research the cost differences between a CDC in China and Europe should be evaluated making the decision more clear. Additionally it should be evaluated whether the possible storage space that is saved in Europe for not using the CDC can be used (opportunity costs).
2. In this project the service levels of the CDC and LDC's remains fixed. However in future research the optimal CDC service level could be evaluated that minimizes the total supply chain costs with the required service level in the LDC.
3. Using palletized containers instead of loos loaded containers. This will yield fewer items per container but it will lower the inbound costs at the local warehouses since unloading palletized containers is faster than unloading and palletizing loose loaded containers.
4. Introducing a periodic review on vendor selection. This should be introduced to ensure that a decision to select a certain vendor made x periods ago is still the best decision. In this review the vendor constraints should be discussed as well since, regardless the supply chain setup reducing the vendor minima's could yield up to 8% cost savings.

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10 Appendices

Appendix I. Preferred supply chain setup calculations

In this chapter the calculations used to determine the preferred supply chain setup are developed. First the algorithm to determine the preferred item flow is described, then the total cost function required to determine this preferred flow is explained. Secondly the algorithm to determine the preferred setting for the lateral shipments is described, followed by the required updates on the total cost function. Thirdly the algorithm to determine the preferred settings for the emergency shipments is described, followed by the required updates on the total cost function. Finally the complete total cost function, including all updates, is given. In order to use these calculations several assumptions were needed. These assumptions are:

1. Normally distributed demand and lead time.
   This assumption is supported with data analysis.
2. Stochastic and independent demand for consecutive periods and different warehouses and items.
3. Average demand is equal for each month of the year
   Trend and seasonality are removed before the cost calculations assuming that this deviation is captured in the forecast method.
4. All demand that cannot be satisfied directly from stock is backordered.
5. There are no constraints regarding storage capacities.
6. Products are non-perishable.
7. Product values are constant.
8. Shipping price (per truck and container) is dependent on shipment size.
9. Shipping two times two pallets is never less expensive than shipping four pallets at once. For truck and container shipments.

I.1 Item flow selection

In order to choose between different setups a total cost function will be used to calculate the expected costs of each setup. This total cost function uses the total cost function developed by Thomas Wijnberg as starting point. However Wijnberg did not have the exact same assumptions, therefore these calculations will be adapted to fit the assumptions and goals of this research. The assumptions made by Wijnberg that are in line with this research are:

1. Normally distributed demand
2. Equal inventory policy over all warehouses but different demand.
3. Demand for consecutive periods and demand for different locations and products are stochastic and independent.
4. Average demand is equal for each month of the year, no distinctions are observed.
5. All demand that cannot be satisfied directly from stock is backordered.
6. Demand is stationary on the daily level per month.
7. There are no constraints regarding storage capacities.
8. Products are non-perishable.
9. Product values are constant.

However, as mentioned before, there were some differences.

1. Suppliers always deliver orders immediately after production and production time is never exceeded.
2. Transshipments between local stock points are not allowed.

3. All lead times are constant and deterministic. Therefore they have no influence on inventory levels via extra safety stock.

Additionally Wijnberg took the possibility of switching between Chinese and European sourcing into account which is out of scope for this research and Wijnberg did not take emergency shipments into account. In Appendix II the calculations provided by Wijnberg are evaluated. Wijnberg's method however gives the opportunity of local optimization instead of system wide optimization. For example with this method it might be interesting for a certain item to be shipped directly to Grossostheim causing the costs of the total system to rise since the minimal order quantity for the CDC will not be met anymore. See Table 10.1

Table 10.1: Example flow selection with local optimization

Warehouse	Dem	MOQ	Individual Optimal flow	Total optimal flow
A	1000	1000	Direct	Indirect
B	200	1000	Indirect	
C	200	1000	Indirect	

Therefore the method by Wijnberg is updated to a recursive algorithm that determines the best item flow. This algorithm is as follows:

1. Set flow for all items and warehouses with demand>0 to indirect delivery.
2. Calculate expected costs.
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to direct delivery.
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch.
5. Repeat step 3 and 4 until all items are delivered to the warehouses via direct delivery.
6. Select the best result of step 4 and retrieve the settings corresponding to this result.

This new procedure and the differences in assumptions require some changes in the calculations. For the first and third difference lead time variance is included in the safety stock calculation, for the second difference (lateral shipments) and for the emergency shipments the calculations for inbound, outbound and transportation will be evaluated in paragraph I.2 and I.3. However first the total costs excluding emergency and lateral shipments will be discussed. These costs are as follows:

$$SCC = \sum_{j=1}^{J} TC_j + IBC_j + SC_j + OBC_j$$

With:

- SCC = Supply Chain Costs
- J = Number of local warehouses + CDC
- TC_j = Transportation costs to warehouse j
- IBC_j = Inbound costs at warehouse j
- SC_j = Storage costs at warehouse j
- OBC_j = Outbound costs at warehouse j

I.1.1 Transportation costs

The transportation costs consist of the sea freight and road transportation costs. The sea freight costs are the costs for transportation from China to the DC's in Europe and the road transportation costs are the costs for shipping items between DC's. When lateral shipments are not included this only contains shipments between the CDC and LDC's. In paragraph I.2 the impact of lateral shipments will be discussed. Swenseth & Godfrey (2002) assume transportation costs only dependent on shipment size. This is in line with this research. Therefore X and Y have been defined as the shipment size of a container and truck respectively. This resulted in the following calculations for transportation costs:

$$TC_j = SF_j + RT_j$$

$$SF_j = \sum_{p=1}^{P} \sum_{x=1}^{X} containers_{pjx} * TCC_{pjx}$$

$$RT_j = \sum_{w=1}^{J} \sum_{y=1}^{Y} trucks_{wjy} * TCT_{wjy}$$

With:

- SF_j = Sea freight costs to warehouse j
- RT_j = Road transportation costs to warehouse j
- P = Number of discharge ports
- X = Number of different container sizes (3) for container sizes 20FT, 40FT and 40FT HC
- $containers_{pjx}$ = Number of containers shipped from port p to warehouse j of size x
- TCC_{pjx} = Costs of shipping one container of size x from port p to warehouse j
- Y = Number of different truck sizes, being the number of pallets fitting in a truck.
- $trucks_{wjy}$ = Number of trucks shipped from warehouse w to warehouse j with y pallets
- TCT_{wjy} = Cost of shipping y pallets from warehouse w to warehouse j

I.1.1.1 Containers

The number of containers shipped per year from port p to warehouse j of shipment size x ($containers_{pjx}$) has been calculated by determining the average number of pallets per shipment from port p to warehouse j ($pallets_{pj}$), then this was fitted into the smallest possible number of containers and multiplied with the shipments per year. In doing so it is assumed that sending 2 containers of a smaller size is always more expensive than one container of the larger size. This resulted in the following container calculation:

$$containers_{pjx} = \left\lceil \frac{pallets_{pjx}}{PpC_x} \right\rceil * \frac{52}{baseR}$$

$$pallets_{pjx} = \left(pallets_{pj} - \sum_{x2=x+1}^{X} \left\lceil \frac{pallets_{pjx2}}{PpC_{x2}} \right\rceil * PpC_{x2} - PpC_{x-1} \right)$$

$$pallets_{pj} = \sum_{i \in I^{pj}} \frac{\mu_{ij}}{PalUn_i} * baseR$$

$$I^{pj} \subseteq I |\, port_i = p \;\cap \left(ItemFlow_{ij} = 0 \cup j = J \right)$$

With:

- $pallets_{pjx}$ = Pallets shipped per review period from port p to warehouse j in a container of size x.
- $baseR$ = base review period (4 weeks)
- PpC_x = Pallets per Container of size x

- $pallets_{pj}$ = Total number of pallets shipped per week from port p to warehouse j
- I = total number of items
- μ_{ij} = Weekly demand of item i at warehouse j
- $PalUn_i$ = Items of type i per pallet
- $port_i$ = Port of discharge of item i
- $ItemFlow_{ij}$ = Flow of item i to warehouse j with 0 and 1 for direct and indirect delivery respectively

I.1.1.2 Trucks

The number of trucks shipped from warehouse w to warehouse j with y pallets per truck ($trucks_{wjy}$) has been calculated by determining the average number of pallets shipped from warehouse w to warehouse j ($pallets_{wj}$), then this was fitted into the smallest possible number of trucks. In doing so it is assumed that sending 2 trucks of a smaller size is always more expensive than sending one truck of a larger size. This resulted in the following truck calculation:

$$trucks_{wjy} = \left\lceil \frac{pallets_{wjy}}{PpT_y} \right\rceil * 52$$

$$pallets_{wjy} = pallets_{wj} - \sum_{y2=y+1}^{Y} \left\lceil \frac{pallets_{wjy2}}{PpT_{y2}} \right\rceil * PpT_{y2} - PpT_{y-1}$$

$$pallets_{wj} = \begin{cases} \sum_{i=1}^{I} \frac{\mu_{ij}}{PalUn_i} [ItemFlow_{ij} = 1] & if \;\; w = J \cap w \neq j \\ 0 & otherwise \end{cases}$$

With:

- $pallets_{wjy}$ = Pallets shipped per week from warehouse w to warehouse j in a truck with y pallets.
- PpT_y = Pallets per Truck of size y
- $pallets_{wj}$ = Total number of pallets shipped per week from warehouse w to warehouse j

I.1.2 Inbound costs

The inbound costs have been calculated for each warehouse individually to allow lateral shipments which influence the inbound (and outbound) costs per warehouse, this impact will be described in paragraph I.2. These costs will be calculated for the incoming trucks and containers separately allowing lateral shipments will increase the number of trucks, the number of containers will remain the same. This resulted in the following calculations:

$$IBC_j = \sum_{x=1}^{X} \left[\sum_{p=1}^{P} containers_{pjx} \right] * inboundCostPerContainer_{jx} + \sum_{y=1}^{Y} \left[\sum_{w=1}^{J} trucks_{wjy} \right] * inboundCostPerTruck_{jy}$$

$$inboundCostPerContainer_{jx} = PpC_x * InboundCostPerPallet_j$$

$$inboundCostPerTruck_{jy} = PpT_y * InboundCostPerPallet_j$$

I.1.3 Storage costs

The storage costs consist of two parts, the opportunity costs, i.e. the money invested in inventory, and the cost of storage for the warehouse space used for the items. This is based on the assumption that if the items would not have been there the money and storage space could have been used for other purposes. Therefore the calculation is as follows:

$$SC_j = \sum_{i=1}^{I} \bar{I}_{ij} * \left((Price_i * interest) + \frac{EuroPerPallet_j}{PalUnit_i} \right)$$

$$\bar{I}_{ij} = SS_{ij} + \frac{\mu_{ij} * R_{ij}}{2}$$

With:

- $\bar{I}_{ij}$ = Average inventory of item i at warehouse j
- $Price_i$ = Purchase price of item i
- $interest$ = Interest percentage used within Office Depot (8.5%)
- $EuroPerPallet_j$ = Costs per year for storing 1 pallet
- SS_{ij} = Safety stock of item i at warehouse j

The safety stock level (SS_{ij}) is calculated with the research of Suavita (2012) as starting point. Suavita (2012) used the research of Donselaar (1990) as main source and updated the calculations to take different review periods at the local and central warehouse into account. These updates are based on personal conversations between Suavita and Donselaar. Since this research has different review periods between the CDC and LDC's as well the updated formulas have been used. However there have been two updates on the calculations provided by Suavita. The formulas suggested by Suavita are:

$$SS_{ij} = -\frac{1}{2}Q_{ij} + k * \sqrt{\frac{1}{12}Q_{ij}^2 + (l_j + R_{ij})\sigma_{ij}^2}$$

$$SS_{i,J} = -\frac{1}{2}Q_{i,J} + k * \sqrt{\frac{1}{12} * Q_{i,J}^2 + \sum_{j=1}^{J-1}(L_i + R_{i,J} - R_{ij}) * \sigma_{ij}^2 + \left\{\sum_{j=1}^{J-1}\sqrt{(l_j + R_{ij})\sigma_{ij}^2 + \sigma_{ij,imb}^2}\right\}^2}$$

- $k = F^{-1}(\alpha')$ = Service factor
- $\alpha' = \frac{2*R_{i,J}*\alpha + R_{ij}}{2*R_{i,J} + R_{ij}}$ = Updated service level for different review period at CDC and LDC
- $\sigma_{ij,imb}^2 = \frac{1}{12}Q^2$ = Variance of imbalance

The first update was required since Suavita calculated the variance of imbalance ($\sigma_{ij,imb}^2$) as $\frac{1}{12}Q^2$. However, according to Donselaar (1990), this only holds when one item at the central warehouse can be used for different final items, which is not the case. Donselaar (1990) provided several calculations for the variance of imbalance, one for systems without a depot and one for systems with a depot, i.e. for items with direct and indirect delivery respectively. These formulas are:

$$\sigma_{ij,imb}^2 = \begin{cases} if\ flow_{ic} = 1 \begin{cases} \frac{1}{12}Q^2 & if\ N \geq 2 \\ 0 & if\ N = 1 \end{cases} \\ if\ flow_{ic} = 0 \begin{cases} \frac{1}{12}Q^2 * \frac{N-1}{N} * \frac{N+2}{N} + \frac{1}{2}\left(\frac{Q_{com}}{N\mu} - 1\right)\frac{(N-1)}{N} * \sigma^2 & if\ Q_{com} \geq N\mu \\ \frac{1}{12}Q^2 * \frac{N-1}{N} * \frac{N+2}{N} & elsewhere \end{cases} \end{cases}$$

With:

- $Q^2 = Q_{ij}^2$ = Order multiple of item i at warehouse j
- $Q_{com} = Q_{iJ}$ = order multiple of item i at central warehouse

Since N is described by Donselaar as the number of divergent items, i.e. items that can be used for multiple final products N equals 1. This already gives zero for both flow options, for the indirect flow (1) this is given, for the direct flow (0) both options are multiplied with N-1 which is zero for N=1. Therefore $\sigma_{ij,imb}^2 = 0$.

The second update on the safety stock calculation was including the lead time variance into the safety stock calculations. This was required since these items have a rather long lead time and first data analysis showed a rather high lead time variance. This is supported in common literature which suggest that longer lead times lead to higher lead time variances. Tallon (1993, pp. 192-193) suggests taking lead time variance into account by updating the safety stock calculation. This update in terms of this research yielded increasing the safety stock with:

$$k * \sqrt{\mu_{ij}^2 * \sigma_{Lij}^2}$$

This approach was also used by Chopra et al. (2004, p. 4). Including these changes resulted into the following safety stock calculations for the local and central DC's:

$$SS_{ij} = -\frac{1}{2}Q_{ij} + k * \sqrt{\frac{1}{12}Q_{ij}^2 + (l_j + R_{ij})\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2}$$

$$SS_{i,J} = -\frac{1}{2}Q_{i,J} + k * \sqrt{\frac{1}{12} * Q_{i,J}^2 + \sum_{j=1}^{J-1}\left[(L_i + R_{i,J} - R_{ij}) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{(l_j + R_{ij})\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2}$$

With:

- j = warehouse number {1,…, J}
- J = central warehouse number (number of local warehouses +1)
- i = item number {1,…,I}
- I = number of items
- l_j = lead time for warehouse j
- R_{ij} = review period of item i at warehouse j
- μ_{ij} = average demand of item i at warehouse j
- SS_{ij} = safety stock of item i at warehouse j

- L_i = lead time of item i
- Q_{ij} = order multiple for item i at warehouse j (note: is not the same Q as in previous chapter)
- σ_{ij}^2 = demand variation of item i at warehouse j
- σ_{LJj}^2 = lead time variance for shipping from central warehouse J to warehouse j
- σ_{Lij}^2 = lead time variance for ordering item i at the corresponding vendor with delivery to warehouse j
- $k = F^{-1}(\alpha')$ = Safety factor
- $\alpha' = \frac{2*R_{i,J}*\alpha+R_{ij}}{2*R_{i,J}+R_{ij}}$
- α = Service level

α is updated to α' to correct for the differences in review period at the local and central warehouses for indirect shipments. This method was developed by Donselaar and reported by Suavita (2012). The service level (α) is the probability that demand can be satisfied from stock, i.e. the probability that the inventory is greater or equal to zero. When assuming that this probability is normally distributed the safety factor (k) can be calculated as followed:

$$k = F^{-1}(\alpha)$$

However Donselaar (1990) claims that, under certain circumstances, a second approach should be considered. This approach is using a uniform distribution and should be used under the circumstance that $\frac{1}{12}Q_{i,j}^2 \geq 4(l_j + R_{i,j})\sigma_{i,j}^2$. In this case Donselaar (1990) suggests the following calculation:

$$k = (\alpha - 0.5) * \sqrt{12}$$

Donselaar (1990) showed that switching between a uniform and normal distribution based on his criteria is valid. He made several simulations with gamma distributed demand while the stock norms are determined based on normal or uniform distributed demand easing the calculations. This simulation showed that the proposed criteria to switch between uniform and normal distribution for the service factor yields the most accurate actual service level compared to the target service level. In this case $(l_j + R_{i,j})\sigma_{i,j}^2$ was the variance component of the safety stock calculation, which in this research is $(l_j + R_{ij})\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2$ for the LDC's and more extended for the CDC. Therefore Var will be used as notation for the variance component of the safety stock.

I.1.4 Outbound costs

The outbound costs have been calculated for each warehouse individually since, as mentioned before, lateral shipments will be investigated which influence the outbound costs per warehouse. This will be discussed in paragraph I.2. These costs will be calculated for the outgoing trucks, allowing lateral shipments will increase the number of trucks, resulting in the following calculations:

$$OBC_j = \sum_{y=1}^{Y}\left[\sum_{w=1}^{J} trucks_{jwy}\right] * OutboundCostPerTruck_{jy}$$

$$outboundCostPerTruck_{jy} = PpT_y * OutboundCostPerPallet_j$$

The outbound cost per pallet have been calculated in the same way as the inbound cost, however there is a difference in the number of pallets picked per hour compared to the number of pallets stored per hour. Therefore the inbound and outbound costs per pallet are not the same.

I.1.5 Concluding

The expected supply chain costs based on the settings of this method are roughly € 0.5 million below the expected costs when the settings resulting from the original method from Wijnberg would have been used. This shows that looking at the supply chain as a whole instead of per warehouse does indeed have an impact on the expected costs and gives a potential profit.

With this new method the pitfall of local optimization seems captured. Additionally updating the calculations included lead time variance. Therefore only the effect of lateral and emergency shipments require some additional changes which will be discussed in the following sections. Evers (1996, p. 120) claims that, for identical facilities with respect to all lead time and demand parameters, the cycle stock will remain the same. Therefore only safety stock levels will be affected in this kind of system. For these shipments a proactive setup was selected since reactive is not possible due to long lead times (for emergency 2 months and for lateral 1-4 days).

I.2 Including proactive lateral shipments

Exactly calculating the setup for lateral shipments is according to Lau et al. (2016), Tagaras & Vlachos (2002) and others mathematically intractable. Therefore the preferred lateral settings will be determined via the algorithm below.

1. Use lateral shipments for all items and warehouses.
2. Calculate expected costs
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to no lateral shipments
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch
5. Repeat step 3 and 4 until no items have lateral shipments
6. Select the best result of step 4 and retrieve the settings corresponding to this result.

In order to use this algorithm the calculations described in the previous paragraph have to be updated. Lau et al. (2016) suggested a roadmap for lateral transshipments. This roadmap evaluates in several steps whether a lateral transshipment should occur and, if so, what amount should be shipped, from which warehouse and if there should be an additional transshipment quantity to correct for possible future shortages. Lau et al. (2016) assume periodic review policy. Their logic on selecting a preferred supplier based on the costs is used, however they take backordering costs into account which are not taken into account in this research. So the other steps (amount and additional quantity) cannot be used.

Naseraldin and Herer (2011, p. 443) show that adding lateral transshipments to the inventory system affects the safety factor k at the local warehouses. They add α_i representing the percentage of demand served by warehouse i and show how to calculate the expected service level of the total system based on the local service levels. Since α is already used for the service level and i represents item instead of warehouse α_i is replaced with δ_j. They present the following formula (with α_i replaced): $\hat{k} = k\sum\sqrt{\delta_j}$. Rewriting the equation gives a formula that can be used to calculate the local safety factors that are required to maintain the overall service level. In order to use the calculation in the rest of the research some notation needs to be changed, resulting in the following calculation:

$$k = \frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}}$$

With:

- $N =$ number of warehouses
- $\hat{k} = F^{-1}(\alpha) =$ total target service level
- $\alpha =$ the required total stock out probability
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N} \mu_x} =$ percentage of demand satisfied from warehouse i

For this calculation they assumed the following:

1. demand on non-overlapping line segments is independent
2. it is beneficial to use lateral transshipments, i.e., the lateral transshipment cost is less than the sum of the holding and shortage costs
3. the lateral transshipment cost is linear in the volume and independent of distance

The only worrying assumption is the second one since there are no shortage costs, however the goal is using optimal number of shipments, therefore if holding costs would be lower than shipment costs no lateral shipments would occur. Therefore this assumption is accepted. Additionally Naseraldin and Herer (2011, p. 444) give a calculation for the total costs including the lateral transshipments. Finally Naseraldin and Herer (2011) introduce an optimization of the reorder levels while assuming equal demand at all locations in order to simplify the calculations, since this is not the case for this research this analysis is not used. The calculation before the simplification however can be used to calculate the expected transshipment costs. The calculation is:

$$T_{ij} * \sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}}\right)\sum_{j=1}^{N}\sqrt{\delta_j}$$

T_{ij} is defined as the lateral transshipment costs to warehouse j. Therefore the rest of the formula is the transshipment quantity to warehouse j. However the costs of lateral transshipments do not depend on the shipment size alone. They also depend on the warehouse shipping the items due to different distances between warehouses. Therefore a preferred supplier or best source (BS) is selected for each item based on the method described by Lau et al. (2016). This method selects a preferred supplier based on the minimal costs. However not all items are on stock at all warehouses, therefore another restriction is that in order to allow lateral shipments both warehouses must have demand and therefore inventory for that item. The transshipment quantity calculated with the above formula is used to determine the expected number of pallets shipped towards the different warehouses. This results in the following calculation for the number of pallets shipped between the different warehouses:

$$pallets_{wj} = \begin{cases} \sum_{i=1}^{I} \frac{\mu_{ij}}{PalUn_i}\left[ItemFlow_{ij} = 1\right] & if\ w = J \cap w \neq j \\ \sum_{i \in BS_{wj}} \frac{\sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N}\sqrt{\delta_j}}\right)\sum_{j=1}^{N}\sqrt{\delta_j}}{PalUn_i} & otherwise \end{cases}$$

$$\left\{BS_{wj} \subseteq I \middle| \mu_{ij} > 0 \cap lat_{ij} \cap pref_{iwj} \cap w \neq J \cap j \neq J\right\}$$

With:

- $BS_{wj} =$ set of all items at warehouse j that have warehouse w as best source for lateral shipments

- $\min\left(TCT_{:j1} | (\mu_{iw} > 0)\right) =$ The warehouse w with the lowest transshipment costs to warehouse j and demand for item i
- lat_{ij} = true if lateral flow allowed for item i at warehouse j

Whether lateral flow is allowed will be determined via the algorithm described at the beginning of this paragraph, which determines the preferred choice for the use of lateral shipments.

I.3 Including proactive emergency shipments

For the use of emergency shipments several choices have to be made regarding the setup. Unfortunately the acquired literature focused on reactive instead of proactive emergency shipments. Therefore the preferred emergency settings will be determined via the algorithm described below.

1. For each item and warehouse combination calculate total costs for having an emergency percentage between $\frac{1}{1000}$ and α with steps of $\frac{1}{1000}$ and select percentage with the lowest total costs.
2. Calculate expected costs with these emergency percentages
3. Calculate for all items and warehouses the expected costs when only that specific item warehouse combination switches to no emergency shipments
4. Select the switch with the lowest expected costs, i.e. the most interesting switch, and save the settings and results of this switch
5. Repeat step 4 and 5 until no items have lateral shipments
6. Select the best result of step 5 and retrieve the settings corresponding to this result.

In order to use this algorithm the calculations described in the previous sections have to be updated. Alfredsson & Verrijdt (1999) describe a reactive system with lateral and emergency deliveries. This idea can be used as base for the reactive emergency shipments by determining the percentage that will be satisfied via emergency shipments beforehand, and reducing the service level with that percentage, which decreases the safety stock. However it triggers at the same time an emergency shipment of that percentage of the demand. Since this emergency shipment has a non-fixed lead time the order should take this into account. This will be done by introducing an emergency safety stock level. This idea was adopted from the research of Tagaras & Vlachos (2002) who described a method for lateral shipments.

Tagaras & Vlachos (2002) define two base stock levels per warehouse, the *regular base stock level* and the *reserve base stock level*. Regular orders are based on the regular base stock level and the lateral transshipments are based on the reserve base stock level. Tagaras & Vlachos (2002) describe the reserve base stock level by: the required inventory to satisfy the demand during the last time units of the review period. This approach allows taking lateral transshipment lead times and review periods into account in the replenishment. The idea of this approach can be used for the emergency shipments. Tagaras give the following reorder level calculations:

$$S_i = \mu_i(L + P) + K_i \sigma_i \sqrt{L + P}$$

$$s_i = \mu_i(P - t) + k_i \sigma_i \sqrt{P - t}$$

With:

- S_i = Regular base stock level
- s_i = Lateral base stock level
- L = Lead time

- P = Review period
- t = time period lateral shipment is started
- K_i = Regular stock safety factor
- k_i = Lateral stock safety factor

The idea behind this is that the lateral shipment should only cover the demand shortage until the next regular order arrives. Since in the case the same idea is used for emergency shipments this base stock calculation can be used. This would give that the emergency base stock level is should be sufficient to fulfill the demand until the regular order arrives. However in this particular case there are overlapping periods, i.e. a new order is placed before the previous order is delivered (R<L) this also hold for the emergency shipments since the emergency lead time is larger than the review period as well. Therefore the emergency base stock level calculation is adapted by switching the review period with the lead time. Additionally the order will be placed at the same time of the regular orders causing the t to be zero. Therefore the base stock calculations are:

$$S_{ij} = \mu_{ij}\left(L_{ij} + R_{ij}\right) + SS_{ij}$$

$$s_{ij} = \mu_i\left(L_{ij}\right) + SSE_{ij}$$

Therefore the emergency safety stock calculation and updated service factor calculation are:

$$SSE_{ij} = -\frac{1}{2}Q_{ij} + kE * \sqrt{\frac{1}{12}Q_{ij}^2 + (l_j)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2}$$

$$SSE_{i,J} = -\frac{1}{2}Q_{i,J} + kE * \sqrt{\frac{1}{12} * Q_{i,J}^2 + \sum_{j=1}^{J-1}\left[\left(L_i - R_{ij}\right) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{(l_j)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2}$$

$$kE = F^{-1}(\alpha)$$

$$k = F^{-1}(\alpha - eP)$$

With:

- eP = Emergency percentage

The service factor for the regular safety stock is reduced with the emergency percentage and the emergency safety stock uses the total target service level. The impact on the total average inventory is terms of cycle stock is zero since demand during lead time is always less or equal to the demand during lead time and review period. The impact based on safety stock is a bit more challenging since $kE \geq k$ and $\sqrt{l} \leq \sqrt{l + R}$. Therefore the highest safety stock value between SS and SSE is selected, giving the following average inventory calculation:

$$\bar{I}_{ij} = \max\left(SS_{ij}, SSE_{ij}\right) + \frac{\mu_{ij} * R_{ij}}{2}$$

Additionally the expected number of emergency shipments has to be determined, this is the emergency percentage multiplied with the demand. This is summed over all items to calculate the expected number of pallets shipped via emergency shipments to each warehouse. This is used to calculate the expected number of 40 FT HC containers since there is no price difference in shipping

20, 40 and 40 FT HC containers via rail transportation. Since the costs and lead times are equal for all vendors the port of discharge can be ignored. This results in the following calculation:

$$containersE_j = \left\lceil \frac{palletsE_{pj} * baseR}{PpC_3} \right\rceil * \frac{52}{baseR}$$

$$palletsE_j = \sum_{i \in I^j} \frac{\mu_{ij} * eP_{ij}}{PalUn_i}$$

$$I^j \subseteq I | \left(ItemFlow_{ij} = 0 \cup j = J \right)$$

Therefore the transportation cost needed to be updated. The new calculations are:

$$TC_j = SF_j + RT_j + TCE_j$$

$$TCE_j = containersE_j * TCCE_j$$

- $TCE_j =$ Total transportation costs emergency shipment to warehouse j
- $containersE_j =$ containers shipped to warehouse j
- $TCCE_j =$ Transportation costs per container to warehouse j

I.4 Final calculations

After all updates on the calculations the final total cost calculations are as follows:

$$SCC = \sum_{j=1}^{J} TC_j + IBC_j + SC_j + OBC_j$$

With:

- SCC = Supply Chain Costs
- J = Number of local warehouses + CDC
- TC_j = Transportation costs to warehouse j
- IBC_j = Inbound costs at warehouse j
- SC_j = Storage costs at warehouse j
- OBC_j = Outbound costs at warehouse j

I.4.1 Transportation costs

$$TC_j = SF_j + RT_j + TCE_j$$

$$SF_j = \sum_{p=1}^{P} \sum_{x=1}^{X} containers_{pjx} * TCC_{pjx}$$

$$RT_j = \sum_{w=1}^{J} \sum_{y=1}^{Y} trucks_{wjy} * TCT_{wjy}$$

$$TCE_j = containersE_j * TCCE_j$$

With:

- j = warehouse number {1,..., J}
- SF_j = Sea freight costs to warehouse j
- RT_j = Road transportation costs to warehouse j
- P = Number of discharge ports
- X = Number of different container sizes (3) for container sizes 20FT, 40FT and 40FT HC
- $containers_{pjx}$ = Number of containers shipped from port p to warehouse j of size x
- TCC_{pjx} = Costs of shipping one container of size x from port p to warehouse j
- Y = Number of different truck sizes, being the number of pallets fitting in a truck.
- $trucks_{wjy}$ = Number of trucks shipped from warehouse w to warehouse j with y pallets
- TCT_{wjy} = Cost of shipping y pallets from warehouse w to warehouse j
- TCE_j = Total transportation costs emergency shipment to warehouse j
- $containersE_j$ = containers shipped to warehouse j
- $TCCE_j$ = Transportation costs per container to warehouse j

I.4.1.1 Containers

$$containers_{pjx} = \left\lceil \frac{pallets_{pjx}}{PpC_x} \right\rceil * \frac{52}{baseR}$$

$$pallets_{pjx} = \left(pallets_{pj} - \sum_{x2=x+1}^{X} \left\lfloor \frac{pallets_{pjx2}}{PpC_{x2}} \right\rfloor * PpC_{x2} - PpC_{x-1} \right)$$

$$pallets_{pj} = \sum_{i \in I^{pj}} \frac{\mu_{ij}}{PalUn_i} * baseR$$

$$I^{pj} \subseteq I |\ port_i = p\ \cap \left(ItemFlow_{ij} = 0 \cup j = J\right)$$

With:

- $pallets_{pjx}$ = Pallets shipped per review period from port p to warehouse j in a container of size x.
- $baseR$ = base review period (4 weeks)
- PpC_x = Pallets per Container of size x
- $pallets_{pj}$ = Total number of pallets shipped per week from port p to warehouse j
- I = total number of items
- μ_{ij} = Weekly demand of item i at warehouse j
- $PalUn_i$ = Items of type i per pallet
- $port_i$ = Port of discharge of item i
- $ItemFlow_{ij}$ = Flow of item i to warehouse j with 0 and 1 for direct and indirect delivery respectively

I.4.1.2 Trucks

$$trucks_{wjy} = \left\lceil \frac{pallets_{wjy}}{PpT_y} \right\rceil * 52$$

$$pallets_{wjy} = pallets_{wj} - \sum_{y2=y+1}^{Y} \left\lceil \frac{pallets_{wjy2}}{PpT_{y2}} \right\rceil * PpT_{y2} - PpT_{y-1}$$

$$pallets_{wj} = \begin{cases} \sum_{i=1}^{I} \frac{\mu_{ij}}{PalUn_i} \left[ItemFlow_{ij} = 1\right] & if\ w = J \cap w \neq j \\ \sum_{i \in BS_{wj}} \frac{\sigma_{ij} * \phi\left(\frac{\hat{k}}{\sum_{j=1}^{N} \sqrt{\delta_j}}\right) \sum_{j=1}^{N} \sqrt{\delta_j}}{PalUn_i} & otherwise \end{cases}$$

$$BS_{wj} = \left\{ \begin{matrix} \left\{ i \in \mathbb{N}_1 \leq I \middle| \mu_{ij} > 0 \cap lat_{ij} \cap TCT_{wj1} = \min\left(TCT_{:j1} | (\mu_{iw} > 0)\right) \right\} & if\ w \neq J \cap j \neq J \\ \{\emptyset\} & otherwise \end{matrix} \right\}$$

$$\alpha' = \begin{cases} \frac{2 * R_{i,J} * \alpha + R_{ij}}{2 * R_{i,J} + R_{ij}} & if\ indirect\ delivery \\ \alpha & if\ direct\ delivery \end{cases}$$

$$\hat{k} = \begin{cases} \left(\alpha' - eP_{ij} - 0.5\right) * \sqrt{12} & if\ \frac{1}{12} Q_{i,j}^2 \geq 4\left(l_j + R_{i,j}\right)\sigma_{i,j}^2 \\ F^{-1}\left(\alpha' - eP_{ij}\right) & otherwise \end{cases}$$

$$k = \begin{cases} \frac{\hat{k}}{\sum_{j=1}^{N} \sqrt{\delta_j}} & if\ lat_{ij} \\ \hat{k} & otherwise \end{cases}$$

With:

- $pallets_{wjy}$ = Pallets shipped per week from warehouse w to warehouse j in a truck with y pallets.
- PpT_y = Pallets per Truck of size y
- $pallets_{wj}$ = Total number of pallets shipped per week from warehouse w to warehouse j
- N = number of warehouses
- α = the required overall service level
- α' = required service level with the impact of the allowed indirect deliveries based on α
- $\hat{k}$ = target service factor with the impact of the allowed emergency shipments based on α'
- k = target service factor with the impact of the allowed lateral shipments based on $\hat{k}$
- $\delta_j = \frac{\mu_j}{\sum_{x=1}^{N} \mu_x}$ = percentage of demand satisfied from warehouse i
- BS_{wji} = set of all items at warehouse j that have warehouse w as best source for lateral shipments
- $\min\left(TCT_{:j1} | (\mu_{iw} > 0)\right)$ = The warehouse w with the lowest transshipment costs to warehouse j and demand for item i
- lat_{ij} = true if lateral flow allowed for item i at warehouse j

I.4.1.3 *Emergency containers*

$$containersE_j = \left\lceil \frac{\sum_{i \in I^j} \frac{\mu_{ij} * eP_{ij}}{PalUn_i} * baseR}{PpC_3} \right\rceil * \frac{52}{baseR}$$

$$I^j \subseteq I \left| \left(ItemFlow_{ij} = 0 \cup j = J \right) \right.$$

I.4.2 Inbound costs

$$IBC_j = \sum_{x=1}^{X} \left\lceil \sum_{p=1}^{P} containers_{pjx} \right\rceil * inboundCostPerContainer_{jx} + \sum_{y=1}^{Y} \left\lceil \sum_{w=1}^{J} trucks_{wjy} \right\rceil * inboundCostPerTruck_{jy}$$

$$inboundCostPerContainer_{jx} = PpC_x * InboundCostPerPallet_j$$

$$inboundCostPerTruck_{jy} = PpT_y * InboundCostPerPallet_j$$

I.4.3 Storage costs

$$SC_j = \sum_{i=1}^{I} \bar{I}_{ij} * \left((Price_i * interest) + \frac{EuroPerPallet_j}{PalUnit_i} \right)$$

$$\bar{I}_{ij} = \max\left(SS_{ij}, SSE_{ij}\right) + \frac{\mu_{ij} * R_{ij}}{2}$$

With:

- i = item number {1,…,I}
- $\bar{I}_{ij}$ = Average inventory of item i at warehouse j
- $Price_i$ = Purchase price of item i
- $interest$ = Interest percentage used within Office Depot (8.5%)
- $EuroPerPallet_j$ = Costs per year for storing 1 pallet

- SS_{ij} = Safety stock of item i at warehouse j
- R_{ij} = review period of item i at warehouse j

$$SS_{ij} = -\frac{1}{2}Q_{ij} + k * \sqrt{\frac{1}{12}Q_{ij}^2 + Var_{ij}}$$

$$Var_{ij} = \left(l_j + R_{ij}\right)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2$$

$$SS_{i,J} = -\frac{1}{2}Q_{i,J} + k * \sqrt{\frac{1}{12} * Q_{i,J}^2 + Var_{iJ}}$$

$$Var_{iJ} = \sum_{j=1}^{J-1}\left[\left(L_i + R_{i,J} - R_{ij}\right) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{\left(l_j + R_{ij}\right)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2$$

$$SSE_{ij} = -\frac{1}{2}Q_{ij} + kE * \sqrt{\frac{1}{12}Q_{ij}^2 + VarE_{ij}}$$

$$VarE_{ij} = \left(l_j\right)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{Lij}^2$$

$$SSE_{i,J} = -\frac{1}{2}Q_{i,J} + kE * \sqrt{\frac{1}{12} * Q_{i,J}^2 + VarE_{iJ}}$$

$$VarE_{iJ} = \sum_{j=1}^{J-1}\left[\left(L_i - R_{ij}\right) * \sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LiJ}^2\right] + \left\{\sum_{j=1}^{J-1}\sqrt{\left(l_j\right)\sigma_{ij}^2 + \mu_{ij}^2 * \sigma_{LJj}^2}\right\}^2$$

$$\widehat{kE} = \begin{cases}(\alpha' - 0.5) * \sqrt{12} \ \ if \ \frac{1}{12}Q_{i,j}^2 \geq 4\left(l_j + R_{i,j}\right)\sigma_{i,j}^2 \\ F^{-1}(\alpha') \qquad\qquad otherwise\end{cases}$$

$$kE = \begin{cases}\dfrac{\widehat{kE}}{\sum_{j=1}^{N}\sqrt{\delta_j}} \ if \ lat_{ij} \\ \widehat{kE} \qquad\qquad otherwise\end{cases}$$

With:

- l_j = lead time for warehouse j
- SS_{ij} = safety stock of item i at warehouse j
- L_i = lead time of item i
- Q_{ij} = order multiple for item i at warehouse j (note: is not the same Q as in previous chapter)
- σ_{ij}^2 = demand variation of item i at warehouse j
- σ_{LJj}^2 = lead time variance for shipping from central warehouse J to warehouse j
- σ_{Lij}^2 = lead time variance for ordering item i at the corresponding vendor with delivery to warehouse j
- α = the required overall service level
- α' = required service level with the impact of the allowed indirect deliveries based on α

- $\widehat{kE}$ = target service factor without the impact of the allowed emergency shipments based on α'
- kE = target service factor with the impact of the allowed lateral shipments based on $\widehat{kE}$

I.4.4 Outbound costs

$$OBC_j = \sum_{y=1}^{Y} \left[\sum_{w=1}^{J} trucks_{jwy} \right] * OutboundCostPerTruck_{jy}$$

$$outboundCostPerTruck_{jy} = PpT_y * OutboundCostPerPallet_j$$

Appendix II. Analysis of method Wijnberg

In order to choose between different setups a total cost function will be used to calculate the expected costs of each setup. This total cost function uses the total cost function developed by Thomas Wijnberg as starting point. However Wijnberg did not have the exact same assumptions, therefore these calculations will be adapted to fit the assumptions and goals of this research. The assumptions made by Wijnberg that are in line with this research are:

1. Normally distributed demand
2. Equal inventory policy over all warehouses but different demand.
3. Demand for consecutive periods and demand for different locations and products are stochastic and independent.
4. Average demand is equal for each month of the year, no distinctions are observed.
5. All demand that cannot be satisfied directly from stock is backordered.
6. Demand is stationary on the daily level per month.
7. There are no constraints regarding storage capacities.
8. Products are non-perishable.
9. Product values are constant.

However, as mentioned before, there were some differences.

1. Suppliers always deliver orders immediately after production and production time is never exceeded.
2. Transshipments between local stock points are not allowed.
3. All lead times are constant and deterministic. Therefore they have no influence on inventory levels via extra safety stock.

Additionally Wijnberg took the possibility of switching between Chinese and European sourcing into account which is out of scope for this research. Furthermore Wijnberg did not take emergency shipments into account.

Therefore several updates on the calculations provided by Wijnberg have been made. In the research of Wijnberg (2015) the superscript F is used for the choice Far East sourcing, this superscript is removed to avoid ambiguity. The remaining notation used by Wijnberg is:

- Carton boxes per pallet item i (C_i)
- Quantity per box per item I (N_i)
- Sea transport tariffs per 40ft container per destination (S^c)
- Road transport tariffs per 40ft container per destination (R^c)
- Road transport tariff per pallet per destination (RP^c)
- Average pallets per warehouse per outbound activity (Z^c)
- Average demand per SKU per day per warehouse (μ_i^c)
- Coefficient of variance per SKU per warehouse (CV_i^c)
- Required service level (SL)
- Average outbound batch per SKU per warehouse (B_i^c)
- Minimum order quantity per SKU (MOQ_i)

- Currency exchange rate dollar/euro (Cur)
- Fill rate container (FR)
- Inventory opportunity cost (decimals) (IO)
- Obsolescence (decimals) (O)

- Lead Time per product per warehouse per variant $\left(LT_i^{b,c}\right)$
- Review time per product per variant (RV_i)

With these input parameters the required calculations can be made, however each formula will be evaluated to avoid unnecessary calculations and overcomplicated formulas. The initial cost calculations for both flows are:

Indirect: $Acquisition + Sea\ Freight + Road\ Transport + Inbound + Outbound + Storage + Inventory\ carrying + Obsolescence$

Direct: $Acquisition + Sea\ Transport + Road\ Transport + Inventory\ carrying + Obsolescence$

These cost factors are evaluated based on relevance and applicability for this research.

- Acquisition

$$P_i = fixed$$

This is fixed since the choice between vendors is out of scope for this research.

- Sea Freight

$$SF_i^c = \frac{S^c}{Q_i * FR}$$

This calculation will slightly change for multiple reasons. First of all the costs for sea freight are known in euros. Secondly the costs for road transport from the ports to the DC's will be included in these costs since this is how these costs are known, therefore the road transport calculation will change as well. The new calculation for sea freight costs will be:

$$SF_i^c = \frac{S^c + R^c}{Q_i * FR} = \frac{transportCostContainer_c}{Q_i * FR}$$

- Road Transport

$$RT_i^{b,c} = \begin{cases} \dfrac{R^c}{Q_i * FR}\ for\ b = d \\ \dfrac{R^c}{Q_i * FR} + \dfrac{RP^c}{C_i * N_i}\ for\ b = i \end{cases} \text{with b = direct (d) or indirect (i) flow}$$

As mentioned in the previous paragraph the road transport from the ports to the DC's is included in the calculations of the sea freight, therefore it is excluded from the road transport costs, this results in having road transport costs of only the costs of shipping between the CDC and the LDC. Additionally the cartons per pallet and items per carton are unknown and therefore replaced by the number of items per pallet ($PalUn_i$). This yields the following calculation for road transport:

$$RT_i^{b,c} = \frac{RP^c}{PalUn_i}$$

- Inbound

$$
IB_i^i = \begin{cases} \left\lceil \frac{\sum_c \mu_i^c * 30}{C_i * N_i} \right\rceil * \frac{3.04 + I_i * 0.24)}{N_i * \sum_c D_i^c * 30} & if\ C_i \leq 10 \\ \left\lceil \frac{\sum_c \mu_i^c * 30}{C_i * N_i} \right\rceil * \frac{3.04 + I_i * 0.19)}{N_i * \sum_c D_i^c * 30} & if\ C_i \leq 20 \\ \left\lceil \frac{\sum_c \mu_i^c * 30}{C_i * N_i} \right\rceil * \frac{3.04 + I_i * 0.17)}{N_i * \sum_c D_i^c * 30} & if\ C_i \leq 30 \\ \left\lceil \frac{\sum_c \mu_i^c * 30}{C_i * N_i} \right\rceil * \frac{3.04 + I_i * 0.16)}{N_i * \sum_c D_i^c * 30} & if\ C_i > 30 \end{cases}
$$

As mentioned before the cartons per pallet and items per carton are unknown and therefore replaced by the number of items per pallet ($PalUn_i$). For the same reason the pallet inbound handling (3.04) and the carton inbound costs ($I_i * 0.24\ for\ C_i \leq 10$, etc.) are combined into one cost factor ($\text{InboundCostPerPallet}_c$). Furthermore the demand is per week instead of per day, therefore *30 is replaced with *52/12 this also corrects for the assumption of 30 days in a month, nevertheless the notation for the demand will remain the same and this correction has to be made for all calculations. In the research of Wijnberg calculations with actual values are made with these formulas (Tool Cost determination Direct-Indirect and Far East-Europe.xlsm, 2015), however checking these values reveals there is a typo in the formula (additionally there is a ")" remaining in the formula indicating a typo). The error is that the number of pallets is multiplied with costs per pallet and the additional costs for picking loose loaded cartons, therefore this is corrected. Furthermore the summation over all warehouses is removed since the decision will be made per warehouse. This results in the following formula:

$$
IB_i^c = \frac{\left\lceil \frac{\mu_i^c * \frac{52}{12}}{PalUn_i} \right\rceil * InboundCostPerPallet_l}{\mu_i^c * \frac{52}{12}}
$$

- Outbound

$$
OB_i^c = \frac{\left\lceil \frac{\mu_i^c * 7}{C_i} \right\rceil * 2.37 + \frac{\mu_i^c * 7}{C_i} * (3.35 + 2.08)}{N_i * \mu_i^c * 7}
$$

For the outbound calculations the demand is, as for inbound, converted to demand per week. Additionally the box quantity is replaced by the pallet quantity since picking a pallet or a single item takes roughly the same time based on conversation with the warehouse manager (Kruistum, 2017).

$$
OB_i^c = \frac{\left\lceil \frac{\mu_i^c}{PalUN_i} \right\rceil * (OutboundCostPerPallet_c)}{\mu_i^c}
$$

- Storage

$$
PS_i^{d,c} = \frac{\left\lceil \frac{\overline{IOH_\iota}}{C_i * N_i} \right\rceil}{\mu_i^c} * 0.197
$$

For the storage the pallet units will be used. Wijnberg (2015) only takes the inventory of the CDC into account, however selecting a direct or indirect flow also affects the inventory in the LDC's since the lead time is reduced. Therefore $\overline{IOH_\iota}$ is replaced by $\overline{IOH_{\iota l_c}}$ and $\overline{IOH_{\iota c}}$ with il_c for inventory of item i at CDC for warehouse c and ιc for inventory of item i at warehouse c. Additionally the Holding costs per Pallet (0.197) is replaced with hp_l to make it possible to have different costs per warehouse. $\overline{IOH_{\iota l_c}}$ and $\overline{IOH_{\iota c}}$ are calculated based on the safety stock plus 0.5 times the demand during the review period.

$$PS_i^{d,c} = \frac{\left\lceil \frac{\overline{IOH_{\iota l_c}}}{PalUn_i} \right\rceil * hp_l + \left\lceil \frac{\overline{IOH_{\iota c}}}{PalUn_i} \right\rceil * hp_c}{\mu_i^c}$$

- Inventory carrying

$$IO_i^{b,c} = P_i * 1.10^{\frac{\left(\frac{\overline{TI}_i^{b,c}}{\mu_i^c}\right)}{365}} = P_i * 1.10^{\frac{\overline{TI}_i^{b,c}}{\mu_i^c * 365}}$$

$\overline{TI}_i^{b,c}$ is not described in the research of Wijnberg (2015), checking the calculations revealed that this should have been $\overline{IT}_i^{b,c}$, in transit items however are out of scope for this research since these costs are not paid by Office Depot (see research proposal).

- Obsolescence

$$O_i^{b,c} = P_i * 0.01$$

In this study obsolescence is ignored, since these calculation yields equal results for the direct and indirect flow.

Based on the previous analysis the remaining calculations for the direct and indirect flow respectively are:

$$Costs_{icD} = \frac{transportCostContainer_c}{Q_i * FR} + \frac{\left\lceil \frac{\overline{IOH_{\iota c}}}{PalUn_i} \right\rceil * hp_c}{\mu_i^c}$$

$$\mathrm{Costs_{icI}} = \frac{transportCostContainer_l}{Q_i * FR} + \frac{RP^c}{PalUn_i} + \frac{\left\lceil \frac{\mu_i^c * \frac{52}{12}}{PalUn_i} \right\rceil * (\mathrm{InboundCostPerPallet}_l)}{\mu_i^c * \frac{52}{12}} + \frac{\left\lceil \frac{\mu_i^c}{PalUN_i} \right\rceil * (OutboundCostPerPallet_c)}{\mu_i^c} + \frac{\left\lceil \frac{\overline{IOH_{\iota l_c}}}{PalUn_i} \right\rceil * hp_l + \left\lceil \frac{\overline{IOH_{\iota c}}}{PalUn_i} \right\rceil * hp_c}{\mu_i^c}$$

This results in two cost factors, one for the direct and one for the indirect flow. The flow with the lowest costs will be used as optimal choice. Therefore the formula is:

$$flow_{ic} = \begin{cases} 0 \; if \; Costs_{icI} > Costs_{icD} \\ 1 \qquad\qquad elsewhere \end{cases}$$

Therefore $flow_{ic} = 0$ yields direct shipments as optimal and $flow_{ic} = 1$ yields indirect shipments as optimal.

Appendix III. Figures

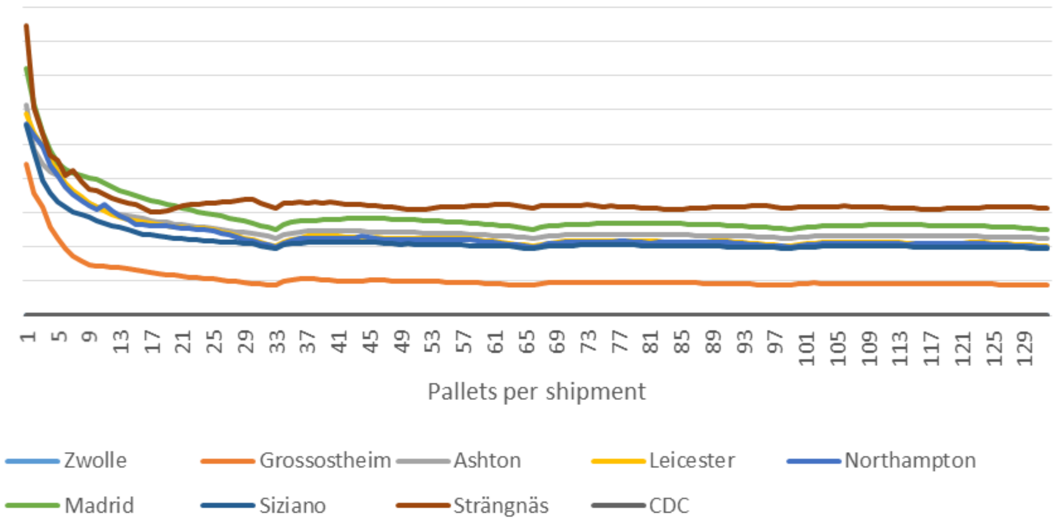

Figure 10.1: Costs per pallet dependent on pallets per shipment

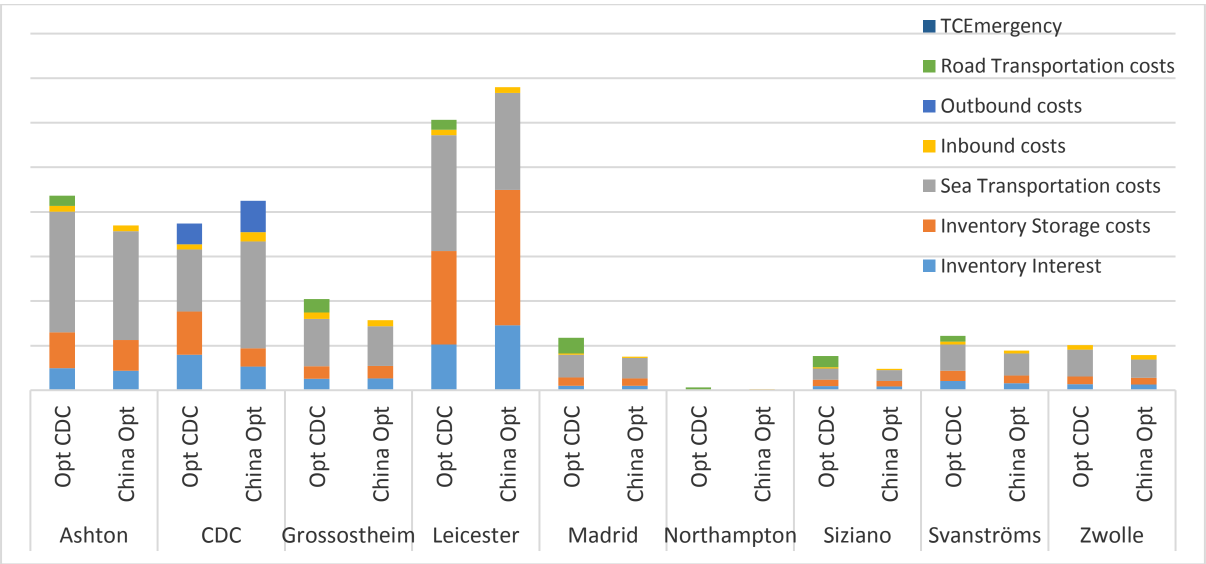

Figure 10.2: CDC Zwolle vs China per warehouse

Appendix IV. Matlab codes

In this appendix the Matlab codes used to determine the preferred supply chain setup are shown. The first code is the main code that has a switch that selects the required data for each step. Switch 0 is the fixed input calculation, switch 4 is the base line calculation, etc. The codes that are referred to in the main code are given after the main code.

IV.1 Main code

```
clear;
clc;
load('inputdata.mat');
load('demandParameters');
load('LTParameters');

Y=33;
transportCostTruck=transportCostTruck(:,:,1:Y);
transportCostTruckBackup=transportCostTruck;

PalletsPerTruck=PalletsPerTruck(1:33);

Run=0;
runs=14;
SST=zeros(runs+1,I,J);
Inv=zeros(runs+1,I,J);
alpha=zeros(I,J)+alpha;
alpha(:,J)=0.75;
alphaBackup=alpha;
latOk=zeros(I,J-1);
emergencyPercentage=zeros(I,J);
emergencyPercentageAir=zeros(I,J);

LTIndirect=repmat(LTIndirectZwolle(:,1)'/7,I,1);
LTSIndirect=repmat(LTIndirectZwolle(:,2)'/7,I,1);
vendorPanLTs=LTS;

LateralCorrection=repmat(sum(sqrt(WeeklyDemand(:,1:J-
1)./repmat(sum(WeeklyDemand(:,1:J-1),2),1,J-1)),2),1,J-1);
CostPerSource=permute(repmat(LateralCosts,1,1,I),[3,1,2])./repmat(do
uble(WeeklyDemand(:,1:J-1)>0),1,1,J-1);
[~,BestSourceTemp]=min(CostPerSource,[],2);
BestSourceTemp2=reshape(BestSourceTemp,I,J-1);
BestSource=zeros(I,J-1,J-1);
EmergencyCosts=zeros(J,1);
for j=1:J-1
    BestSource(:,:,j)=(repmat(1:J-
1,I,1)==BestSourceTemp2(:,j)).*(WeeklyDemand(:,1:J-1)>0);
    EmergencyCosts(j,1)=EmergencyInput{j+1,2}-
transportCostContainer(j,3);
end
EmergencyCosts(J,1)=EmergencyInput{J+1,2}-
transportCostContainer(J,3);

AirCostsMin=zeros(J,5);
AirCostsPKG=zeros(J,5);
AirCostsFixed=zeros(J,1);
for j=1:J
```

```
    for temp=6:2:14
        AirCostsMin(j,temp/2-2)=EmergencyInput{j+1,temp};
        AirCostsPKG(j,temp/2-2)=EmergencyInput{j+1,temp+1};
    end
    AirCostsFixed(j,1)=EmergencyInput{j+1,5};
end
itemWeight=zeros(I,1);
for i=1:I
    if length(itemInput{i,12})==1
        itemWeight(i,1)=itemInput{i,12};
    end
end
save('airInput','itemWeight','AirCostsFixed','AirCostsPKG','AirCosts
Min');

while Run<=runs
    disp([Run,runs]);
    switch Run
        case 0 % actual
            load('initials.mat');
            trialtrucks=trucks;

trucks=trialtrucks(:,:,1:33)+trialtrucks(:,:,34:66)+trialtrucks(:,:,
67:99)+trialtrucks(:,:,100:132);

trucks(:,:,33)=trucks(:,:,33)+sum(trialtrucks(:,:,34:66),3)+2*sum(tr
ialtrucks(:,:,67:99),3)+3*sum(trialtrucks(:,:,100:132),3);

            SST(1,:,:)=SafetyStock;
            Inv(1,:,:)=Inventory;
            LT=LTP;
            basereviewperiod=4;

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
            TCEmergency=zeros(J,1);
        case 1 % current setup
            SST(2,:,:)=SafetyStock;
            LT=LTP;
            basereviewperiod=4;

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 2 % New SS calculated With LTP
            LT=LTP;
            basereviewperiod=4;

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
```

```
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 3 % New SS calculated with LTA
            LT=LTA;
            basereviewperiod=4;

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 4 % No CDC used
            LT=LTA;
            basereviewperiod=4;
            ItemFlow=zeros(I,J-1);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 5 % Full CDC used
            LT=LTA;
            basereviewperiod=4;
            ItemFlow=ones(I,J-1);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 6 % Best CDC usage
            LT=LTA;
            basereviewperiod=4;
            %             %
load('itemflow2outputdata2','ItemFlow');
%
ItemFlow=itemflow3(emergencyPercentageAir,LTSIndirect,LateralCorrect
ion,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCos
ts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPo
rt,itemMinimal,interest,LT,Run,I,J,P,X,Y,itemInput,itemPalunit,palle
tsPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,o
utboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPa
llet,itemPrice);
%             save('ItemFlowstuff','ItemFlow');
            load('ItemFlowstuff','ItemFlow');

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
        case 7 % No CDC + lateral
            LT=LTA;
            basereviewperiod=4;
```

```
            ItemFlow=zeros(I,J-1);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
%             latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice);
%             save('LateralStuf','latOk');
            load('LateralStuf','latOk');
            useLateral=sum(sum(latOk))>0;
        case 8 % No CDC + EmergencyRail
            LT=LTA;
            basereviewperiod=4;
            ItemFlow=zeros(I,J-1);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);

            latOk=zeros(I,J-1);
            EmOk=cat(2,1-ItemFlow,ones(I,1));
%             emergencyPercentage =
CalcEmergencyOpt(LTSIndirect,LateralCorrection,EmOk,BestSource,Emerg
encyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperiod,
LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,
I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostCon
tainer,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pallets
PerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             save('emergencyStuff','emergencyPercentage');
            load('emergencyStuff','emergencyPercentage');
            useEmergency=sum(sum(emergencyPercentage))>0;
        case 9 % No CDC + EmergencyAir
            LT=LTA;
            basereviewperiod=4;
            ItemFlow=zeros(I,J-1);
            latOk=zeros(I,J-1);
            emergencyPercentage=zeros(I,J);
            EmOk=cat(2,1-ItemFlow,ones(I,1)).*(itemWeight>0);
%             emergencyPercentageAir =
CalcEmergencyOptAir(LTSIndirect,LateralCorrection,EmOk,BestSource,Em
ergencyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperi
od,LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFl
ow,I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCost
Container,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pall
etsPerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             save('emergencyStuffAir','emergencyPercentageAir');
```

```
            load('emergencyStuffAir','emergencyPercentageAir');
            useEmergencyAir=sum(sum(emergencyPercentageAir))>0;
        case 10 % Best CDC + lateral + EmergencyAir + 2 week review
period
            LT=LTA;
            basereviewperiod=2;
            emergencyPercentage=zeros(I,J);
            emergencyPercentageAir=zeros(I,J);
            latOk = zeros(I,J-1);

ItemFlow=itemflow3(emergencyPercentageAir,LTSIndirect,LateralCorrect
ion,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCos
ts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPo
rt,itemMinimal,interest,LT,Run,I,J,P,X,Y,itemInput,itemPalunit,palle
tsPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,o
utboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPa
llet,itemPrice);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
%             if useLateral
%                 latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice);
%             end
%             if useEmergency
%                 EmOk=cat(2,1-ItemFlow,ones(I,1));
%                 emergencyPercentage =
CalcEmergencyOpt(LTSIndirect,LateralCorrection,EmOk,BestSource,Emerg
encyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperiod,
LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,
I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostCon
tainer,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pallets
PerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             end
%             if useEmergencyAir
%                 EmOk=cat(2,1-ItemFlow,ones(I,1)).*(itemWeight>0);
%                 emergencyPercentageAir =
CalcEmergencyOptAir(LTSIndirect,LateralCorrection,EmOk,BestSource,Em
ergencyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperi
od,LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFl
ow,I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCost
Container,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pall
etsPerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             end
        case 11 % Opt CDC China + lateral + Emergency + 4 week
review period
```

```
            %% LT,LTIndirect,LTS,LTSIndirect,% outboundCost
J,inboundCost J
            transportCostTruck(J,:,:)=0;
            LT=vendorLTa;
            LTIndirect=portdestLTa(:,1:J-1)/7;
            LTS=vendorLTs;
            LTSIndirect=portdestLTs(:,1:J-1)/7;
%             LTSIndirect=sqrt((portdestLTs(:,1:J-
1)/7).^2+(repmat(LTIndirectZwolle(:,2)'/7,I,1)).^2);
            EmOk=zeros(I,J);
            latOk =zeros(I,J-1);
            emergencyPercentage=zeros(I,J);
            emergencyPercentageAir=zeros(I,J);
            basereviewperiod=4;

ItemFlow=itemflow3(emergencyPercentageAir,LTSIndirect,LateralCorrect
ion,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCos
ts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPo
rt,itemMinimal,interest,LT,Run,I,J,P,X,Y,itemInput,itemPalunit,palle
tsPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,o
utboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPa
llet,itemPrice);

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
%             if useLateral
%                 latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice);
%             end
%             if useEmergency
%                 emergencyPercentage =
CalcEmergencyOpt(LTSIndirect,LateralCorrection,EmOk,BestSource,Emerg
encyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperiod,
LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,
I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostCon
tainer,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pallets
PerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             end
%             if useEmergencyAir
%                 emergencyPercentageAir =
CalcEmergencyOptAir(LTSIndirect,LateralCorrection,EmOk,BestSource,Em
ergencyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperi
od,LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFl
ow,I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCost
Container,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pall
etsPerTruck,transportCostTruck,EuroPerPallet,itemPrice);
%             end
```

```
        case 12 % No CDC + lateral*.5
            LT=LTA;
            LTIndirect=repmat(LTIndirectZwolle(:,1)'/7,I,1);
            LTSIndirect=repmat(LTIndirectZwolle(:,2)'/7,I,1);
            LTS=vendorPanLTs;

            EmOk=zeros(I,J);
            emergencyPercentage=zeros(I,J);
            emergencyPercentageAir=zeros(I,J);
            basereviewperiod=4;
            ItemFlow=zeros(I,J-1);
            transportCostTruck=transportCostTruckBackup;
            transportCostTruck(1:J-
1,:,:)=transportCostTruckBackup(1:J-1,:,:)*.5;

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
%              latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice);
%              save('LateralStufHalf','latOk');
            load('LateralStufHalf','latOk');
            useLateralHalf=sum(sum(latOk))>0;
        case 13
            %% change dependend on own choices!!
            useCDC=1;
            useLateral=0;
            useEmergency=0;
            useEmergencyAir=0;

            transportCostTruck=transportCostTruckBackup;
            LT=LTA;
            LTIndirect=repmat(LTIndirectZwolle(:,1)'/7,I,1);
            LTSIndirect=repmat(LTIndirectZwolle(:,2)'/7,I,1);
            LTS=vendorPanLTs;

            EmOk=zeros(I,J);
            latOk =zeros(I,J-1);
            emergencyPercentage=zeros(I,J);
            emergencyPercentageAir=zeros(I,J);
            basereviewperiod=4;
            ItemFlow=zeros(I,J-1);
            if useCDC

ItemFlow=itemflow3(emergencyPercentageAir,LTSIndirect,LateralCorrect
ion,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCos
ts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPo
rt,itemMinimal,interest,LT,Run,I,J,P,X,Y,itemInput,itemPalunit,palle
```

```
tsPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,o
utboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPa
llet,itemPrice);
            end

[WeeklyDemand,DemandSigma]=CalcDemandCDC(WeeklyDemand,DemandSigma,It
emFlow,J);
            R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);
            if useLateral
                latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice);
            end
            if useEmergency
                emergencyPercentage =
CalcEmergencyOpt(LTSIndirect,LateralCorrection,EmOk,BestSource,Emerg
encyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperiod,
LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,
I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostCon
tainer,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pallets
PerTruck,transportCostTruck,EuroPerPallet,itemPrice);
            end
            if useEmergencyAir
                emergencyPercentageAir =
CalcEmergencyOptAir(LTSIndirect,LateralCorrection,EmOk,BestSource,Em
ergencyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperi
od,LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFl
ow,I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCost
Container,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pall
etsPerTruck,transportCostTruck,EuroPerPallet,itemPrice);
            end
    end
    alpha=alphaBackup-emergencyPercentage-emergencyPercentageAir;

VAR=CalcVAR(LTSIndirect,Run,LTS,WeeklyDemand,ItemFlow,R,LT,LTIndirec
t,DemandSigma,I,J);

[KtF,Q,kCDC]=CalcKtf_LTij_Q(VAR,ItemFlow,LateralCorrection,latOk,R,i
temMultiple,itemBatch,alpha,J);

    if Run>1
        SafetyStock=CalcSafetyStock(VAR,I,J,KtF,kCDC,Q);
        SST(Run+1,:,:)=SafetyStock;
    end
    if Run>0

[containers,palletsJ]=CalcContainers(palletsPerContainer,itemPort,ba
sereviewperiod,itemPalunit,X,P,I,J,WeeklyDemand,ItemFlow);
```

```
trucks=CalcTrucks(latOk,itemPalunit,KtF,DemandSigma,Q,VAR,BestSource
,transportCostTruck,palletsJ,Y,I,J,LateralCorrection,ItemFlow);

        if max(max(emergencyPercentage))>0

TCEmergency=emergencyCosts(J,X,EmergencyCosts,palletsPerContainer,ba
sereviewperiod,palletsJ,emergencyPercentage);
            LTTemp=LT;
            LTTemp(:,J)=LT(:,J)-1;% -1 week for review period in CDC
VAR calculation

VARTemp=CalcVAR(LTSIndirect*0,Run,LTS,WeeklyDemand,ItemFlow,R*0,LTTe
mp,LTIndirect*0,DemandSigma,I,J);

[KtF2,~,kCDC2]=CalcKtf_LTij_Q(VARTemp,ItemFlow,LateralCorrection,lat
Ok,R,itemMultiple,itemBatch,alpha+emergencyPercentage,J);
            SSEmergency=CalcSafetyStock(VARTemp,I,J,KtF2,kCDC2,Q);
        elseif max(max(emergencyPercentageAir))>0

TCEmergency=AirCalculations(WeeklyDemand,emergencyPercentageAir,base
reviewperiod);
            LTTemp=LT-2;% -2 weeks for -t, i.e. order is placed 2
weeks later in the process
            LTTemp(:,J)=LT(:,J)-1;% -1 week for review period in CDC
VAR calculation

VARTemp=CalcVAR(LTSIndirect,Run,LTS,WeeklyDemand,ItemFlow,R*0,LTTemp
,LTIndirect,DemandSigma,I,J);

[KtF2,~,kCDC2]=CalcKtf_LTij_Q(VARTemp,ItemFlow,LateralCorrection,lat
Ok,R,itemMultiple,itemBatch,alpha+emergencyPercentageAir,J);
            SSEmergency=CalcSafetyStock(VARTemp,I,J,KtF2,kCDC2,Q);
        else
            SSEmergency=zeros(I,J);
            TCEmergency=zeros(J,1);
        end
        Inventory=max(SafetyStock,SSEmergency)+WeeklyDemand.*R./2;
        Inv(Run+1,:,:)=Inventory;
    end
    if Run<4
        LTtemp=LT/7;
        LTtemp(ItemFlow>0)=LTIndirect(ItemFlow>0);

alpha=CalcServiceLevel(alpha,I,J,Q,Inventory,SafetyStock,R,LTtemp,We
eklyDemand,DemandSigma);
    end
    %%

[TCS,TCR,IBC,SCI,SCS,OBC,RPC]=CalcCosts(P,J,transportCostTruck,trans
portCostContainer,PalletsPerTruck,trucks,outboundCost,inboundCost,co
ntainers,palletsPerContainer,WeeklyDemand,itemPrice,Inventory,itemPa
lunit,EuroPerPallet);
    SCC=TCS+TCR+TCEmergency+IBC+SCI*interest+SCS+OBC;
    Run=Run+1;
```

```
    alphaPrint=(sum(alpha(:,1:J-1).*WeeklyDemand(:,1:J-1),'omitnan'))./(sum(WeeklyDemand(:,1:J-1)));
    alphaPrint(1,J)=sum(sum(alpha(:,1:J-1).*WeeklyDemand(:,1:J-1),'omitnan'))./sum(sum(WeeklyDemand(:,1:J-1)));

xlswrite('matlabOutput',[{datestr(datetime('now'))},{'SCI'},{'SCI*interest'},{'SCS'},{'TCS'},{'IBC'},{'OBC'},{'IBC+OBC'},{'TCR'},{'TCEmergency'},{'SCC'},{'RPC'},{'SCC+RPC'},{'Alpha'}],Run,'A1:N1')

xlswrite('matlabOutput',[SCI,SCI*interest,SCS,TCS,IBC,OBC,IBC+OBC,TCR,TCEmergency,SCC,RPC,SCC+RPC,alphaPrint'],Run,'B2:N10');

    printEuro(SCI,'Inventory Value');
    printEuro(SCI*interest,'Inventory Interest');
    printEuro(SCS,'Inventory Storage costs');
    printEuro(TCS,'Sea Transportation costs');
    printEuro(IBC,'Inbound costs');% CDC + DC
    printEuro(OBC,'Outbound costs');
    printEuro(IBC+OBC,'inbound + outbound costs');
    printEuro(TCR,'Road Transportation costs');
    printEuro(TCEmergency,'TCEmergency');
    printEuro(SCC,'SupplyChain added costs');
    printEuro(RPC,'RawProduct costs');
    printEuro(SCC+RPC,'Total costs');

    printPercentage(sum(sum(latOk)/(I*(J-1))),'Lateral');
    if sum(sum(emergencyPercentageAir))>0

printPercentage(sum(sum(emergencyPercentageAir.*WeeklyDemand))./sum(sum(WeeklyDemand)),'EmergencyAir');
    else

printPercentage(sum(sum(emergencyPercentage.*WeeklyDemand))./sum(sum(WeeklyDemand)),'EmergencyRail');
    end
    printPercentage(sum(sum(alpha(:,1:J-1).*WeeklyDemand(:,1:J-1),'omitnan'))./sum(sum(WeeklyDemand(:,1:J-1))),'Alpha');
    fprintf('\n');
end
```

IV.2 Total cost calculation based on specific settings

```
function
SCC2=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCorrectio
n,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCosts
,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPort
,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPaluni
t,palletsPerContainer,transportCostContainer,WeeklyDemand,DemandSigm
a,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostTruck,Eu
roPerPallet,itemPrice)
%      run CalcDemandCDC.m;
WeeklyDemand(:,J)=sum(WeeklyDemand(:,1:J-1).*ItemFlow,2);
DemandSigma(:,J)=sqrt(sum(DemandSigma(:,1:J-1).^2.*ItemFlow,2));

%      run CalcReviewPeriod.m;
R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit);

alpha=alphaBackup-emergencyPercentage-emergencyPercentageAir;%
lateralPercentage is done in CalcKtf_LTij_Q
VAR=CalcVAR(LTSIndirect,Run,LTS,WeeklyDemand,ItemFlow,R,LT,LTIndirec
t,DemandSigma,I,J);
[KtF,Q,kCDC]=CalcKtf_LTij_Q(VAR,ItemFlow,LateralCorrection,latOk,R,i
temMultiple,itemBatch,alpha,J);

%      run CalcSafetyStock.m;
SafetyStock=CalcSafetyStock(VAR,I,J,KtF,kCDC,Q);

%      run CalcContainers.m;
[containers,palletsJ]=CalcContainers(palletsPerContainer,itemPort,ba
sereviewperiod,itemPalunit,X,P,I,J,WeeklyDemand,ItemFlow);

%      run CalcTrucks.m;
trucks=CalcTrucks(latOk,itemPalunit,KtF,DemandSigma,Q,VAR,BestSource
,transportCostTruck,palletsJ,Y,I,J,LateralCorrection,ItemFlow);

if max(max(emergencyPercentage))>0

TCEmergency=emergencyCosts(J,X,EmergencyCosts,palletsPerContainer,ba
sereviewperiod,palletsJ,emergencyPercentage);
    LTTemp=LT;
    LTTemp(:,J)=LT(:,J)-1;% -1 week for review period in CDC VAR
calculation

VARTemp=CalcVAR(LTSIndirect*0,Run,LTS,WeeklyDemand,ItemFlow,R*0,LTTe
mp,LTIndirect*0,DemandSigma,I,J);

[KtF2,~,kCDC2]=CalcKtf_LTij_Q(VARTemp,ItemFlow,LateralCorrection,lat
Ok,R,itemMultiple,itemBatch,alpha+emergencyPercentage,J);
    SSEmergency=CalcSafetyStock(VARTemp,I,J,KtF2,kCDC2,Q);
elseif max(max(emergencyPercentageAir))>0

TCEmergency=AirCalculations(WeeklyDemand,emergencyPercentageAir,base
reviewperiod);
    LTTemp=LT-2;% -2 weeks for -t, i.e. order is placed 2 weeks
later in the process
```

```
    LTTemp(:,J)=LT(:, J)-1;% -1 week for review period in CDC VAR
calculation

VARTemp=CalcVAR(LTSIndirect,Run,LTS,WeeklyDemand,ItemFlow,R*0,LTTemp
,LTIndirect,DemandSigma,I,J);

[KtF2,~,kCDC2]=CalcKtf_LTij_Q(VARTemp,ItemFlow,LateralCorrection,lat
Ok,R,itemMultiple,itemBatch,alpha+emergencyPercentageAir,J);
    SSEmergency=CalcSafetyStock(VARTemp,I,J,KtF2,kCDC2,Q);
else
    SSEmergency=zeros(I,J);
    TCEmergency=zeros(J,1);
end

%inventory
Inventory=max(SafetyStock,SSEmergency)+WeeklyDemand.*R./2;

%      run CalcCosts.m;
[TCS,TCR,IBC,SCI,SCS,OBC,~]=CalcCosts(P,J,transportCostTruck,transpo
rtCostContainer,PalletsPerTruck,trucks,outboundCost,inboundCost,cont
ainers,palletsPerContainer,WeeklyDemand,itemPrice,Inventory,itemPalu
nit,EuroPerPallet);
% SCC=TCS+TCR+IBC+SCI*interest+SCS+OBC;

SCC=TCS+TCR+IBC+SCI*interest+SCS+OBC+TCEmergency;

SCC2=sum(SCC);
```

IV.2.1 Review period calculation

```
function R =
CalcReviewPeriod(ItemFlow,basereviewperiod,itemMinimal,WeeklyDemand,
itemVendor,I,itemPrice,itemInput,palletsPerContainer,itemPalunit)
ItemFlowExt=cat(2,1-ItemFlow,ones(I,1));

R=1+ItemFlowExt.*(basereviewperiod-1);
% R=basereviewperiod*ones(I,9);

RT=itemMinimal./(WeeklyDemand.*ItemFlowExt);
R=max(RT.*RT./RT,R);

vendor=[31168,31157];
minimal=6000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=31166;
minimal=10000*0.9444;
perdest=0;
R1=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Week
lyDemand,perdest);
minimal=10000;
R2=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice./ite
mPrice,WeeklyDemand,perdest);
R=min(R1,R2);

vendor=31849;
minimal=3000*0.9444;
perdest=0;
R1=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Week
lyDemand,perdest);
minimal=500;
R2=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice./ite
mPrice,WeeklyDemand,perdest);
R=min(R1,R2);

vendor=31062;
minimal=6000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

% vendor=30669;
% minimal=3000*0.9444;
% perdest=1;
%
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=30785;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);
```

```
vendor=31159;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=31614;
minimal=5000*0.9444;
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=32909;
minimal=8000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=31843;
minimal=5000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=33531;
minimal=8000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=30786;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=30785;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=34027;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=34630;
minimal=15000*0.9444;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=34984;
```

```
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=34950;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=35006;
minimal=palletsPerContainer(1,1);
perdest=1;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,1./itemPalunit,
WeeklyDemand,perdest);

vendor=34630;
minimal=15000;
perdest=0;
R=includeMOV(ItemFlowExt,itemVendor,R,vendor,minimal,itemPrice,Weekl
yDemand,perdest);

vendor=33609;
minimal=100;
perdest=1;
itemVendortemp=itemVendor;
for i=1:I
    if itemVendor(i)==33609

itemVendortemp(i)=itemVendor(i).*contains(itemInput{i,8},'91X122');
    end
end
R=includeMOV(ItemFlowExt,itemVendortemp,R,vendor,minimal,itemPrice./
itemPrice,WeeklyDemand,perdest);
itemVendortemp=itemVendor;
for i=1:I
    if itemVendor(i)==33609

itemVendortemp(i)=itemVendor(i).*contains(itemInput{i,8},'117X152');
    end
end
R=includeMOV(ItemFlowExt,itemVendortemp,R,vendor,minimal,itemPrice./
itemPrice,WeeklyDemand,perdest);
% disp(sum(sum(R)));
```

IV.2.2 Variance component calculation

```
function
VAR=CalcVAR(LTSIndirect,Run,LTS,WeeklyDemand,ItemFlow,R,LT,LTIndirec
t,DemandSigma,I,J)
VAR=zeros(I,J);
ITFL=logical(ItemFlow);

LTij=LT(:,1:J-1)/7;
LTij(ITFL)=LTIndirect(ITFL);
if Run~=2
    LTStDev=((LTS(:,1:J-
1).*(~ItemFlow)./7)+LTSIndirect.*ItemFlow).*(WeeklyDemand(:,1:J-
1)>0);
else
    LTStDev=zeros(I,J-1);
end
VAR(:,1:J-1)=(LTij+R(:,1:J-1)).*DemandSigma(:,1:J-
1).^2+WeeklyDemand(:,1:J-1).^2.*LTStDev.^2;

tempR=R(:,1:J-1);
tempDemandSigma=DemandSigma(:,1:J-1);
tempWeeklyDemand=WeeklyDemand(:,1:J-1);

sum1I=sum(((LT(:,J)./7+R(:,J)-
tempR).*tempDemandSigma.^2+tempWeeklyDemand.^2.*(LTS(:,J).^2./7)).*I
temFlow,2);
sum2I=sum((sqrt((LTij+tempR).*tempDemandSigma.^2+tempWeeklyDemand.^2
.*LTStDev.^2)).*ItemFlow,2);

VAR(:,J)=(sum1I+sum2I.^2);
```

IV.2.3 Service factor, lead time and batch quantity calculation

```
function
[KtF,Q,kCDC]=CalcKtf_LTij_Q(VAR,ItemFlow,LateralCorrection,latOk,R,i
temMultiple,itemBatch,alpha,J)
ITFL=logical(ItemFlow);

Q=repmat(itemMultiple,1,J);
Qi=repmat(itemBatch,1,J);
Q(ITFL)=Qi(ITFL);

IfThenElse=1/12.*Q(:,1:J-1).^2<(4.*(VAR(:,1:J-1)));

alphaRed=alpha(:,1:J-1);
alphat=((2.*R(:,J).*alphaRed+4)./(2.*R(:,J)+4).*ItemFlow)+alphaRed.*
~ItemFlow;

KtFTemp4=(alphat-0.5)*sqrt(12);
KtFTemp4(IfThenElse)=norminv(alphat(IfThenElse));

alphatemp=(2.*R(:,J).*alpha(:,J)+min(R,[],2))./(2.*R(:,J)+min(R,[],2
));

IfThenElseCDC=1/12.*Q(:,J).^2<4.*(VAR(:,J));

kCDC=(alphatemp-0.5)*sqrt(12);
kCDC(IfThenElseCDC)=norminv(alphatemp(IfThenElseCDC));

KtF=KtFTemp4./max(LateralCorrection.*latOk,1);
```

IV.2.4 Safety stock calculation

```
function SS=CalcSafetyStock(VAR,I,J,KtF,kCDC,Q)
SS=zeros(I,J);
tempQ=Q(:,1:J-1);
SSTstep=sqrt(1/12.*tempQ.^2+VAR(:,1:J-1));
SST=-0.5.*tempQ+KtF.*SSTstep;
SS(:,1:J-1)=SST;
SS(:,J)=-0.5.*Q(:,J)+kCDC.*sqrt(1./12.*Q(:,J).^2+VAR(:,J));
SS(SS<0)=0;
```

IV.2.5 Container calculation

```
function
[containers,palletsJ]=CalcContainers(palletsPerContainer,itemPort,ba
sereviewperiod,itemPalunit,X,P,I,J,WeeklyDemand,ItemFlow)
palletsJ=WeeklyDemand./itemPalunit;

palletJ2=palletsJ.*basereviewperiod.*cat(2,1-ItemFlow,ones(I,1));
palletsPJ=zeros(P,J);
for p=1:P
    palletsPJ(p,:)=sum(palletJ2(itemPort==p,:));
end
palletsPJX=zeros(P,J,X);
PPCpjx=permute(repmat(palletsPerContainer,1,P,J),[2,3,1]);
for x=X:-1:1
    if x~=1
        palletsPJX(:,:,x)=palletsPJ-
sum(ceil(palletsPJX./PPCpjx).*PPCpjx,3)-palletsPerContainer(x-1);
    else
        palletsPJX(:,:,x)=palletsPJ-
sum(ceil(palletsPJX./PPCpjx).*PPCpjx,3);
    end
    palletsPJX(palletsPJX<0)=palletsPJX(palletsPJX<0)>0;
end
containers=ceil(palletsPJX./PPCpjx)*52/basereviewperiod;
```

IV.2.6 Truck calculation

```
function
trucks=CalcTrucks(latOk,itemPalunit,KtF,DemandSigma,Q,VAR,BestSource
,transportCostTruck,palletsJ,Y,I,J,LateralCorrection,ItemFlow)
trucks=zeros(J,J,Y);

tempTrucks=sum(ceil(palletsJ(:,1:J-1)*10)/10*.8.*ItemFlow,1);
for j=1:J-1
    temp=tempTrucks(j);
    if ceil(temp)>0
        while ceil(temp)>length(transportCostTruck(1,1,:))

trucks(J,j,length(transportCostTruck(1,1,:)))=trucks(J,j,length(tran
sportCostTruck(1,1,:)))+52;
            temp=temp-length(transportCostTruck(1,1,:));
        end
        trucks(J,j,ceil(temp))=trucks(J,j,ceil(temp))+52;
    end
end

if sum(sum(latOk))>0
    IfThenElse=1/12.*Q(:,1:J-1).^2<4.*VAR(:,1:J-1);

    LatCorr=zeros(I,J-1);
    LatCorr(IfThenElse)=normcdf(KtF(IfThenElse));
    LatCorr(~IfThenElse)=(KtF(~IfThenElse))/sqrt(12)+0.5;

    iftrial=latOk.*LatCorr;

    for j=1:J-1
        temp2345=BestSource(:,:,j).*DemandSigma(:,j).*iftrial(:,j);

temp2=sum(ceil((temp2345.*LateralCorrection)./itemPalunit*10)/10*.8,
1,'omitnan');

        for j2=1:J-1
            if temp2(j2)>0
                while
ceil(temp2(j2))>length(transportCostTruck(1,1,:))

trucks(j2,j,length(transportCostTruck(1,1,:)))=trucks(j2,j,length(tr
ansportCostTruck(1,1,:)))+52;
                    temp2(j2)=temp2(j2)-
length(transportCostTruck(1,1,:));
                end

trucks(j2,j,ceil(temp2(j2)))=trucks(j2,j,ceil(temp2(j2)))+52;
            end
        end
    end
end
```

IV.2.7 Rail emergency cost calculation

```
function
TCEmergency=emergencyCosts(J,X,EmergencyCosts,palletsPerContainer,ba
sereviewperiod,palletsJ,emergencyPercentage)
emergencyPalletsPW=palletsJ.*emergencyPercentage;
emergencyPalletsPR=sum(emergencyPalletsPW.*basereviewperiod,1);
containersEmergency=ceil(emergencyPalletsPR/palletsPerContainer(X))*
52/basereviewperiod;
TCEmergency=zeros(J,1);
for j=1:J
    TCEmergency(j,1)=containersEmergency(j).*EmergencyCosts(j,1);
end
```

IV.2.8 Air emergency cost calculation

```
function
AirCostsActual=AirCalculations(WeeklyDemand,emergencyPercentageAir,b
asereviewperiod)
load('airInput');

KGS=sum(WeeklyDemand.*basereviewperiod.*itemWeight.*emergencyPercent
ageAir,1)';
PD=KGS.*AirCostsPKG;
PD2=AirCostsFixed+sum(max(PD,AirCostsPKG),2);
AirCostsActual=PD2.*(KGS>0)/basereviewperiod.*52;
```

IV.2.9 Total cost calculation

```
function
[TCS,TCR,IBC,SCI,SCS,OBC,RPC]=CalcCosts(P,J,transportCostTruck,trans
portCostContainer,PalletsPerTruck,trucks,outboundCost,inboundCost,co
ntainers,palletsPerContainer,WeeklyDemand,itemPrice,Inventory,itemPa
lunit,EuroPerPallet)

containersJX=reshape(sum(containers,1),J,length(containers(1,1,:)));
TCSJX=containersJX.*transportCostContainer;
TCS=sum(TCSJX,2);

TCRWJY=trucks.*transportCostTruck;
TCR=sum(sum(TCRWJY,3),1)';
SCI=sum(Inventory.*itemPrice)';
SCS=sum(Inventory./itemPalunit.*transpose(EuroPerPallet))';
RPC=[sum(WeeklyDemand(:,1:J-1).*itemPrice*52)';0];

inboundcostPerPallet=inboundCost(:,1);

IBCpCoTX=permute(repmat(palletsPerContainer'.*inboundcostPerPallet,[
1,1,P]),[3 1 2]);
IBCcontainers=transpose(sum(sum(containers.*IBCpCoTX,3),1));

IBCpToTY=permute(repmat(PalletsPerTruck.*inboundcostPerPallet,[1,1,J
]),[3 1 2]);
IBCTrucks=transpose(sum(sum(trucks.*IBCpToTY,3),1));

IBC=IBCcontainers+IBCTrucks;
OutboundcostPerPallet=outboundCost(:,1);
OBCpToTY=permute(repmat(PalletsPerTruck.*OutboundcostPerPallet,[1,1,
J]),[3 1 2]);
OBC=transpose(sum(sum(permute(trucks,[2,1,3]).*OBCpToTY,3),1));
```

IV.3 Iterative item flow selection

```
function
ItemFlow=itemflow3(emergencyPercentageAir,LTSIndirect,LateralCorrect
ion,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCos
ts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPo
rt,itemMinimal,interest,LT,Run,I,J,P,X,Y,itemInput,itemPalunit,palle
tsPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,o
utboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPa
llet,itemPrice)

ItemFlowBest=WeeklyDemand(:,1:J-1)>0;
ItemFlow=ItemFlowBest;

SCCBest=zeros(sum(sum(ItemFlowBest)),1);
allItemFlows=cell(sum(sum(ItemFlowBest)),1);
count=1;
allItemFlows{count,1}=ItemFlow;
SCCBest(count,1)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,Late
ralCorrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Em
ergencyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVen
dor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInpu
t,itemPalunit,palletsPerContainer,transportCostContainer,WeeklyDeman
d,DemandSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transport
CostTruck,EuroPerPallet,itemPrice);

while sum(sum(ItemFlowBest))>0
    SCCFlow=zeros(I,J-1)+10^10;
    parfor xitemflow=1:I
        for yitemflow=1:J-1
            ItemFlow=ItemFlowBest;
            if ItemFlow(xitemflow,yitemflow)>0
                ItemFlow(xitemflow,yitemflow)=0;

SCCFlow(xitemflow,yitemflow)=calcSCCFlow(emergencyPercentageAir,LTSI
ndirect,LateralCorrection,latOk,BestSource,alphaBackup,itemBatch,ite
mMultiple,EmergencyCosts,emergencyPercentage,basereviewperiod,LTIndi
rect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,
X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostContainer
,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,PalletsPerTru
ck,transportCostTruck,EuroPerPallet,itemPrice);
            end
        end
    end
    count=count+1;
    SCCBest(count,1)=min(min(SCCFlow));
    [~,a]=min(min(SCCFlow));
    [~,b]=min(SCCFlow(:,a));
    ItemFlowBest(b,a)=0;
    allItemFlows{count,1}=ItemFlowBest;
    SCCFlow(b,a)=10^10;
    while SCCBest(count-1,1)>min(min(SCCFlow))
        count=count+1;
        %         SCCBest(count,1)=min(min(SCCFlow));
        [~,a]=min(min(SCCFlow));
        [~,b]=min(SCCFlow(:,a));
```

```
        %         ItemFlowBest(b,a)=0;
        ItemFlow=ItemFlowBest;
        ItemFlow(b,a)=0;

temp=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCorrectio
n,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCosts
,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPort
,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPaluni
t,palletsPerContainer,transportCostContainer,WeeklyDemand,DemandSigm
a,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostTruck,Eu
roPerPallet,itemPrice);
        if temp<SCCFlow(count-1)
            ItemFlowBest(b,a)=0;
            SCCBest(count)=temp;
            SCCFlow(b,a)=10^10;
            allItemFlows{count,1}=ItemFlowBest;
        else
            count=count-1;
            break;
        end
    end
    %
allWhsCF=sum(SCCFlow.*ItemFlowBest,2).*min((SCCFlow<SCCBest(count-
1,1))+(ItemFlowBest==0),[],2);
    %     [c,d]=min(allWhsCF./allWhsCF./allWhsCF);
    %     if c>0
    %         ItemFlowBest(d,:)=0;
    %     end
    %
ItemFlowBest=ItemFlowBest.*repmat(min((SCCFlow<SCCBest(count-
1,1))+(ItemFlowBest==0),[],2)==0,1,J-1);
    %     ItemFlowBest=ItemFlowBest.*(SCCBest(count-1,1)<SCCFlow);
    %     disp(sum(sum(ItemFlowBest)));
end
ItemFlow=ItemFlowBest;
SCCBest(count+1,1)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,La
teralCorrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,
EmergencyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemV
endor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemIn
put,itemPalunit,palletsPerContainer,transportCostContainer,WeeklyDem
and,DemandSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transpo
rtCostTruck,EuroPerPallet,itemPrice);
allItemFlows{count+1,1}=ItemFlowBest;

[~,a]=min(SCCBest.*SCCBest./SCCBest);
ItemFlow=allItemFlows{a};
% disp(sum(sum(ItemFlowBest)));
% disp(min(SCCBest.*SCCBest./SCCBest));
figure;
plot(SCCBest.*SCCBest./SCCBest);
save('ItemFlowstuff2');
```

IV.4 Iterative lateral shipment selection

```
function latOk =
CalcLateralOpt(emergencyPercentageAir,LTSIndirect,LateralCorrection,
BestSource,EmergencyCosts,emergencyPercentage,itemBatch,itemMultiple
,alphaBackup,basereviewperiod,LTIndirect,itemVendor,itemPort,itemMin
imal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPalunit,pallet
sPerContainer,transportCostContainer,WeeklyDemand,DemandSigma,LTS,ou
tboundCost,inboundCost,PalletsPerTruck,transportCostTruck,EuroPerPal
let,itemPrice)
% latOkBest=zeros(I,J-1);
latOkBest=reshape(sum(BestSource,2),I,J-1).*(WeeklyDemand(:,1:J-
1)>0);
% for j=1:J-1
%     for i=1:I
%         j2=BestSourceTemp2(i,j);
%         if WeeklyDemand(i,j2)>0
%             latOkBest(i,j)=1;
%         end
%     end
% end
% latOkBest=latOkBest.*(WeeklyDemand(:,1:J-1)>0);
latOk=latOkBest;
SCCBest=zeros(sum(sum(latOkBest)),1);
SCCBest(1,1)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralC
orrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Emerge
ncyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,
itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,it
emPalunit,palletsPerContainer,transportCostContainer,WeeklyDemand,De
mandSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCost
Truck,EuroPerPallet,itemPrice);
count=1;
allLats=cell(sum(sum(latOkBest)),1);
allLats{count,1}=latOkBest;
while sum(sum(latOkBest))>0
    SCCLat=zeros(I,J-1)+10^10;
    parfor i=1:I
        for j=1:J-1
            latOk=latOkBest;
            if latOk(i,j)>0
                latOk(i,j)=0;

SCCLat(i,j)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCo
rrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Emergen
cyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,i
temPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,ite
mPalunit,palletsPerContainer,transportCostContainer,WeeklyDemand,Dem
andSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostT
ruck,EuroPerPallet,itemPrice);
            end
        end
    end
    count=count+1;
    SCCBest(count,1)=min(min(SCCLat));
    [~,a]=min(min(SCCLat));
    [~,b]=min(SCCLat(:,a));
```

```
    latOkBest(b,a)=0;
    SCCLat(b,a)=10^10;
    allLats{count,1}=latOkBest;
    while SCCBest(count-1,1)>min(min(SCCLat))
        count=count+1;
        [~,a]=min(min(SCCLat));
        [~,b]=min(SCCLat(:,a));
        latOk=latOkBest;
        latOk(b,a)=0;

temp=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCorrectio
n,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,EmergencyCosts
,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,itemPort
,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,itemPaluni
t,palletsPerContainer,transportCostContainer,WeeklyDemand,DemandSigm
a,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostTruck,Eu
roPerPallet,itemPrice);
        if temp<SCCLat(count-1)
            latOkBest(b,a)=0;
            SCCBest(count)=temp;
            SCCLat(b,a)=10^10;
            allLats{count,1}=latOkBest;
        else
            count=count-1;
            break;
        end
    end
    %     allWhsL=sum(SCCLat.*latOkBest(:,1:J-
1),2).*min((SCCLat<SCCBest(count-1,1))+(latOkBest(:,1:J-
1)==0),[],2);
    %     [c,d]=min(allWhsL./allWhsL./allWhsL);
    %     if c>0
    %         latOkBest(d,:)=0;
    %     end
    latOkBest(:,1:J-1)=latOkBest(:,1:J-
1).*(SCCBest(count,1)~=SCCLat);
end
[~,a]=min(SCCBest.*SCCBest./SCCBest);
latOk=allLats{a};
% [~,latOk]=min(SCCBest);
% latOk=latOk.*((latOk-1)/1000);
figure;
plot(SCCBest.*SCCBest./SCCBest);
save('CalcLateralOptResults');
```

IV.5 Iterative rail emergency shipment selection

```
function emergencyPercentageBest =
CalcEmergencyOpt(LTSIndirect,LateralCorrection,EmOk,BestSource,Emerg
encyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperiod,
LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,
I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostCon
tainer,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pallets
PerTruck,transportCostTruck,EuroPerPallet,itemPrice)
iters=floor(max(max(alphaBackup))*1000);
emergencyPercentageBest=zeros(I,J);
emergencyPercentageAir=zeros(I,J);
for i=1:I
    for j=1:J
        if EmOk(i,j)>0&&WeeklyDemand(i,j)>0
            SCCBestem=zeros(iters,1);
            parfor emergencyPercentage2=1:iters
                emergencyPercentage=emergencyPercentageBest;
                emergencyPercentage(i,j)=emergencyPercentage2/1000;

SCCBestem(emergencyPercentage2)=calcSCCFlow(emergencyPercentageAir,L
TSIndirect,LateralCorrection,latOk,BestSource,alphaBackup,itemBatch,
itemMultiple,EmergencyCosts,emergencyPercentage,basereviewperiod,LTI
ndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J
,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostContai
ner,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,PalletsPer
Truck,transportCostTruck,EuroPerPallet,itemPrice);
            end
            [~,Number]=min(SCCBestem.*SCCBestem./SCCBestem);
            emergencyPercentageBest(i,j)=EmOk(i,j)*((Number)/1000);
        end
    end
end
emergencyPercentageBackup=emergencyPercentageBest; %#ok<NASGU>
count=1;
SCCBest=zeros(sum(sum(emergencyPercentageBest>0)),1);
emergencyPercentage=emergencyPercentageBest;
SCCBest(count,1)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,Late
ralCorrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Em
ergencyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVen
dor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInpu
t,itemPalunit,palletsPerContainer,transportCostContainer,WeeklyDeman
d,DemandSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transport
CostTruck,EuroPerPallet,itemPrice);
allEms=cell(sum(sum(emergencyPercentageBest>0)),1);
allEms{count,1}=emergencyPercentageBest;
while sum(sum(emergencyPercentageBest))>0
    SCCEm=zeros(I,J)+10^10;
    parfor i=1:I
        for j=1:J
            emergencyPercentage=emergencyPercentageBest;
            if emergencyPercentage(i,j)>0
                emergencyPercentage(i,j)=0;

SCCEm(i,j)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCor
rection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Emergenc
```

```
yCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,it
emPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,item
Palunit,palletsPerContainer,transportCostContainer,WeeklyDemand,Dema
ndSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostTr
uck,EuroPerPallet,itemPrice);
            end
        end
    end
    count=count+1;
    SCCBest(count,1)=min(min(SCCEm));
    [~,a]=min(min(SCCEm));
    [~,b]=min(SCCEm(:,a));
    emergencyPercentageBest(b,a)=0;
%     SCCEm(b,a)=10^10;
    allEms{count,1}=emergencyPercentageBest;
end
[~,a]=min(SCCBest.*SCCBest./SCCBest);
emergencyPercentageBest=allEms{a,1};
save('CalcEmergencyOptResults');
```

IV.6 Iterative air emergency shipment selection

```
function emergencyPercentageBestAir =
CalcEmergencyOptAir(LTSIndirect,LateralCorrection,EmOk,BestSource,Em
ergencyCosts,latOk,itemBatch,itemMultiple,alphaBackup,basereviewperi
od,LTIndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFl
ow,I,J,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCost
Container,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,Pall
etsPerTruck,transportCostTruck,EuroPerPallet,itemPrice)
iters=floor(max(max(alphaBackup))*1000);
emergencyPercentageBestAir=zeros(I,J);
emergencyPercentage=zeros(I,J);
for i=1:I
    for j=1:J
        if EmOk(i,j)>0&&WeeklyDemand(i,j)>0
            SCCBestem=zeros(iters,1);
            parfor emergencyPercentage2=1:iters
                emergencyPercentageAir=emergencyPercentageBestAir;

emergencyPercentageAir(i,j)=emergencyPercentage2/1000;

SCCBestem(emergencyPercentage2)=calcSCCFlow(emergencyPercentageAir,L
TSIndirect,LateralCorrection,latOk,BestSource,alphaBackup,itemBatch,
itemMultiple,EmergencyCosts,emergencyPercentage,basereviewperiod,LTI
ndirect,itemVendor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J
,P,X,Y,itemInput,itemPalunit,palletsPerContainer,transportCostContai
ner,WeeklyDemand,DemandSigma,LTS,outboundCost,inboundCost,PalletsPer
Truck,transportCostTruck,EuroPerPallet,itemPrice);
            end
            [~,Number]=min(SCCBestem.*SCCBestem./SCCBestem);

emergencyPercentageBestAir(i,j)=EmOk(i,j)*((Number)/1000);
        end
    end
end
emergencyPercentageBackup=emergencyPercentageBestAir; %#ok<NASGU>
count=1;
SCCBest=zeros(sum(sum(emergencyPercentageBestAir>0)),1);
emergencyPercentageAir=emergencyPercentageBestAir;
SCCBest(count,1)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,Late
ralCorrection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Em
ergencyCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVen
dor,itemPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInpu
t,itemPalunit,palletsPerContainer,transportCostContainer,WeeklyDeman
d,DemandSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transport
CostTruck,EuroPerPallet,itemPrice);
allEms=cell(sum(sum(emergencyPercentageBestAir>0)),1);
allEms{count,1}=emergencyPercentageBestAir;
while sum(sum(emergencyPercentageBestAir))>0
    SCCEm=zeros(I,J)+10^10;
    parfor i=1:I
        for j=1:J
            emergencyPercentageAir=emergencyPercentageBestAir;
            if emergencyPercentageAir(i,j)>0
                emergencyPercentageAir(i,j)=0;
```

```
SCCEm(i,j)=calcSCCFlow(emergencyPercentageAir,LTSIndirect,LateralCor
rection,latOk,BestSource,alphaBackup,itemBatch,itemMultiple,Emergenc
yCosts,emergencyPercentage,basereviewperiod,LTIndirect,itemVendor,it
emPort,itemMinimal,interest,LT,Run,ItemFlow,I,J,P,X,Y,itemInput,item
Palunit,palletsPerContainer,transportCostContainer,WeeklyDemand,Dema
ndSigma,LTS,outboundCost,inboundCost,PalletsPerTruck,transportCostTr
uck,EuroPerPallet,itemPrice);
            end
        end
    end
    count=count+1;
    SCCBest(count,1)=min(min(SCCEm));
    [~,a]=min(min(SCCEm));
    [~,b]=min(SCCEm(:,a));
    emergencyPercentageBestAir(b,a)=0;
%     SCCEm(b,a)=10^10;
    allEms{count,1}=emergencyPercentageBestAir;
end
[~,a]=min(SCCBest.*SCCBest./SCCBest);
emergencyPercentageBestAir=allEms{a,1};
save('CalcEmergencyOptResultsAir');
```