MASTER

Spare parts inventory control at Océ
design of an inventory control concept for a spare parts network at Océ

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“De schrijver werd door Océ-Technologies B.V. in staat gesteld een onderzoek te verrichten dat mede aan dit rapport ten grondslag ligt.
Océ-Technologies B.V. aanvaardt geen verantwoordelijkheid voor de juistheid van de in dit rapport vermelde gegevens, beschouwingen en conclusies, die geheel voor rekening van de schrijver komen.”

Abstract

Océ Technologies and Canon have merged in 2009 after which Océ is restricted to use Canon's network for the distribution of spare parts. For this new network, a new inventory control concept is designed in this research. In scope of the research is the upstream part of the new service supply chain with one central warehouse, also facing direct customer demands, and six regional warehouses. Demands can be emergency requests, that have high priority, or regular replenishment orders, that have low priority. At both echelons an (S,c)-policy is used. This means that replenishments are generated according to an order-up-to level and a critical level is used to differentiate between the two demand streams. Emergency shipments from the central warehouse are used if a regional warehouse cannot satisfy an emergency request. Regular shipments from the central warehouse to the regional warehouses can be sent by sea or air transportation. A model has been developed to optimize the parameter settings per part and per location, while meeting the aggregate fill rate constraints at every location. The model is based on the item approach. An ABC-classification based on price and demand rate has been used to differentiate between parts. An analysis with test data shows that large cost savings can be made by determining the transportation mode per part with the model. Using critical levels and a single stock pool at the central warehouse is found to be efficient.

Management Summary

In 2009, Canon has taken over Océ in order to create the world's leading group in the printing industry. Together, Canon and Océ offer a large variety of copying and printing systems. Canon focuses more on the office imaging segment and Océ focuses mostly on the professional production printing segment. Most of the machines sold by Océ are sold with a service contract, in which it is specified within which time period Océ needs to repair the machine in the case it is broken. Spare parts are needed for these repairs. With the integration with Canon, Océ's spare parts distribution network has changed towards the situation where the central warehouse of Océ in Venlo (CSC) serves the Regional Headquarters (RSHQ's) of Canon. The RSHQ's serve the downstream part of the service supply chain (Field Stock Locations). In order to optimize the inventory control in this service supply chain, Océ will control the inventory levels of Océ parts at the RSHQ's in the near future.

Océ does not know how the inventories of the CSC and the RSHQ's should be controlled. Therefore the following research objective has been formulated.

Develop a multi-item, multi-echelon inventory control policy for the CSC and the RHSQ's in order to minimize total costs against given service level constraints and implement this in a tool.

Design methodology

The design methodology of Bertrand (2013) is used for this design. In the first phase (conceptual design), functional requirements are specified, design parameters are determined and scientific models are selected that are used for the model. In the next phase (detailed design), the models are worked out in detail. Thereafter the design is implemented in a tool in the integration phase and the results are analyzed.

Results

The analysis of the current situation and operations revealed the following most important features of Océ's service supply chain:

- Two-echelon system
- Two demand types:
  - Regular replenishment orders
  - Emergency requests
- An emergency shipment from the CSC is possible if an emergency request at an RSHQ cannot be fulfilled
- Two possible transportation modes from the CSC to the RSHQ's (Sea and Air)

These features led to the determination of an efficient inventory control policy with an order-up-to level (S) and a critical level (c) at the CSC and RSHQ's. An aggregate fill rate constraint of 97% has to be met at the RSHQ's and at the CSC for demand from the Field Stock Locations, dealers and OEM-partners. The choice between sea and air shipments should be determined for every part and every location separately. At the CSC, one single stock pool should be used to serve all of the demands faced there.

A scientific model that fits very well to the service supply chain of Océ cannot be found in literature. Therefore two models have been selected, that together represent Océ's network quite well. These are the models of Deshpande et al. (2013) and Enders et al. (2014). Some adaptations have been made to these models to represent the reality even better. An iteration between the models is used to find an integral solution. An item classification, based on the currently used XYZ-method, has been used to differentiate between parts on the basis of the price and demand rate of the parts.

The designed model has been implemented in a tool that can be used to determine the order-up-to levels and critical levels for every part at the CSC and RSHQ's. The performance of the generated solution has been compared to simulation results, which revealed that the designed model sets the parameters conservatively. This means that in practice the costs may be expected to be even lower than estimated by the model and the fill rate performance will be higher than estimated. Unfortunately, the output of the model could not be compared with actual performance and costs that were made in the past under the current planning method, because these figures are not transparent for the RSHQ's. A comparison only at the CSC would have no value, since the performance at the CSC is dependent on the parameter settings at the RSHQ's. The model has been tested with demand data of about 15 months of the Océ ColorWave 600. The test results show that with a yearly costs total of € 64.600 the aggregate fill rate constraint of 97% can be met.

This is 7% lower compared to the costs when the CSC uses a separate stock pool for the EMEA-network, which is opted for the future. The model with critical levels yields a yearly costs total that is 2,5% lower than the model without critical levels.

Conclusions

From this research the following conclusions are drawn:

- An efficient control concept is designed for the spare parts inventory control of the CSC and RSHQ's
- With the designed model and policy, the total yearly costs are 7% lower compared to the policy where CSC uses a separate stock pool for the EMEA-network, which is opted for the future.
- Using the tool to determine the transportation mode for every part separately leads to a yearly costs total that is 35% lower compared to using sea transportation as standard mode.
- The model with critical levels yields a yearly costs total that is 2,5% lower than the model without critical levels.

Recommendations

The following recommendations are made after this research:

- Implement the new inventory control policy at the CSC and the RSHQ's. To be successful:
  - Include all RSHQ's in S-CUBE.
  - Register demand classes accurately for every demand that is faced.
  - Store the dimensions of every part (volume and weight).
- Pool the stocks for every demand stream together at the CSC.
- Use the tool to determine the standard transportation mode per part separately.

- Implement the critical levels at the CSC for sure. At the RSHQ's the value of this is lower.
- For future research: find an approximation method for the model with generally distributed demand; develop a multi-item model that uses heterogeneous customer classes, which means that emergency shipments apply for one demand class and backordering for the other class.

Preface

This thesis is the final work of my master study Operations Management and Logistics at the Eindhoven University of Technology. After following master courses for one and a half year and completing the 'Honors Track in Design' as an addition to the standard program, I started with my graduation project at Océ. After my graduation I will continue at the Eindhoven University of Technology with the post-master study Logistic Management Systems at a spot that is made available by Océ.

I fulfilled my graduation project at the department SCM Service Parts 1 that is responsible for the planning and control of the spare parts of Océ at the central warehouse in Venlo. At the time during my graduation project, Océ was in a transition phase towards a new spare parts network. This new network originates from the merger in 2009 between Canon and Océ. This same merger enabled my project in which I developed a tool to determine parameter settings in the new network. This assignment turned out to be very challenging, because many factors come together in the network of Océ.

Without the help and assistance of several people I would not have been able to complete this challenging assignment successfully. First of all I would like to thank Niels Houben, my first supervisor at Océ, for his great commitment to my project, for his critical questions, smart suggestions, feedback and enthusiasm. Secondly I would like to thank Roger Vliegen for giving me the opportunity to finish my master study with this very challenging and interesting assignment at Océ and for his critical feedback on my work. I am also very grateful for the opportunity to be present at the visit to Océ of representatives of Canon, who came from Japan to Venlo to determine the collaboration terms between Océ and Canon with regards to the service supply chain.
I would also like to thank all employees of the other departments to whom I have asked questions and who were all very willing to help me.
In addition I would like to thank all employees of SCM Service Parts 1 for giving me a very pleasant working environment. From the start of my graduation project I have enjoyed my time at Océ.

From the Eindhoven University of Technology I would like to thank Geert-Jan van Houtum. First of all for his trust in me and also for his great knowledge about the field of service logistics. His comments and feedback really helped me during the project, especially when difficult complexities arose. I would also like to thank Engin Topan, my second supervisor at the university, for his help with the problems that I had and for his feedback on my work.

Finally I would like to thank my family and friends, who always supported me during my study and graduation project and I would especially like to thank Manon, for supporting me during my time at Océ, when I had to work hard on my project and had to spent a lot of time on my study.

Nicky van der Weijden

Venlo, June 2014

Table of Contents

1 Company description

In this chapter the company Océ Technologies is introduced. The focus of this introduction is on the recent take-over by Canon, which made Océ a Canon Company and on the service logistics organization of Océ.

1.1 Océ: a Canon Company

In 2009, Canon has taken over Océ in order to create the world's leading group in the printing industry. The strategic rationale for the merger between the two companies is to create a strong joint enterprise capable of long term successes by building upon each other's strengths. The Canon Group operates a large worldwide sales and marketing network. Access to this network is now provided for Océ, which creates opportunities for Océ, especially in Asia possibilities have increased for Océ as a result of the merger with Canon. Océ has expertise in the areas of production printing and wide format printing and operates a well-working business services model. Together, Océ and Canon offer complementary technologies and products in the printing industry.

1.2 Mission

Before the integration with Canon, the mission of Océ technologies was the following (Océ Technologies B.V., 2008):

"Océ enables its customers to manage their documents efficiently and effectively by offering innovative print and document management products and services for professional environments."

Although this is a statement made before the integration with Canon, this is still the mission that Océ pursues and communicates to their employees. To achieve this mission, Océ offers a varying spectrum of excellent printing products together with contracts with their customers in which the services for the customers are specified.

1.3 After-sales service

An important part of the services specified in the contracts with the customers is formed by the maintenance activities that Océ carries out to keep the products at their customers' sites up and running. Service level agreements are made with the customers, in which the level of service provided by Océ is specified. In order to be able to meet these service levels Océ uses a large network of stock points and technicians who carry out maintenance activities at the customers.

1.4 Supply chain integration

The integration between Océ and Canon has not been executed at one single moment. The largest part of the supply chain integration has taken place at the start of 2013. Due to the integration the Océ Headquarters now delivers the spare parts to the six RSHQ's outside Europe. The stock at these RSHQ's is owned by the RSHQ's themselves and the planning and control of the inventory at the RSHQ's is also done by the RSHQ's now. As a consequence, the regional inventory planning is now feeding the inventory planning at the Headquarters of Océ. The supply chain integration in Europe is still in a transition phase. Currently, Océ is still serving the distribution network that it has been operating in Europe before the integration with Canon, although administratively all parts flow via Canon EMEA.

1.5 Organizational structure

The part of the organization of Canon which is responsible for serving the printing and document services industry consists of two main organizational entities. These are Production Printing Products (PPP) and Office Imaging Printing (OIP). OIP is responsible for the production and service of document printers for the office market, this is mainly the Canon assortment added with Océ products for document printing. PPP is an organizational entity which is formed by Océ-Technologies only and is responsible for printers for professional users. Océ is responsible for PPP and for the OIP-assortment of Océ-products. Within PPP there are several main departments of which two are of interest for this project: the strategic business units (SBU's) Wide Format Printing Services (SBU WFPS) and Commercial Printing (SBU CP), which are responsible for two different types of products and PPP Logistics. WFPS is located in Venlo, the Netherlands and CP is located in Poing, Germany. PPP Logistics facilitates these SBU's in both Venlo and Poing.

The logistics of the service parts of all printing products of Océ are controlled by PPP Logistics. An organizational chart of this department can be found in Figure 1.1. The index numbers 1 and 2 that are used for some departments represent Venlo and Poing respectively.

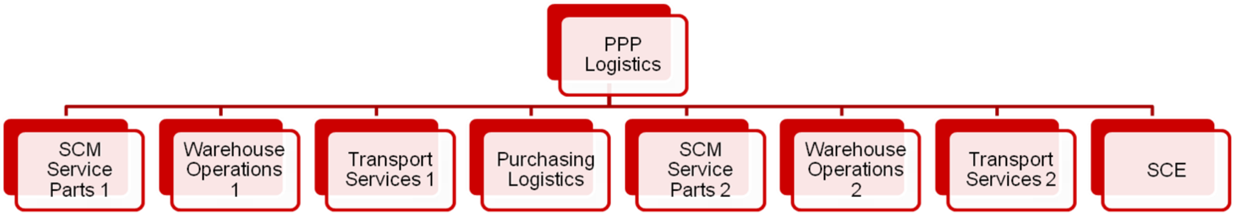

Figure 1.1: Organizational chart of PPP-Logistics

The assignment for this Master's Thesis originates from the department SCM Service Parts 1. This department is responsible for the planning and control of spare parts inventories in Venlo. The department is structured on the basis of functions. Service Parts & Expendables OIP (SP&E-OIP) is responsible for the inbound flow of spare parts that are used for the OIP-assortment; Service Parts & Expendables WFPS (SP&E-WFPS) is responsible for the inbound flow of spare parts that are used for the WFPS-assortment; Customer Services Service Parts and Expendables (Customer Service SP&E) is responsible for the outbound flow of the spare parts of all Océ-products. An organizational chart can be found in Figure 1.2.

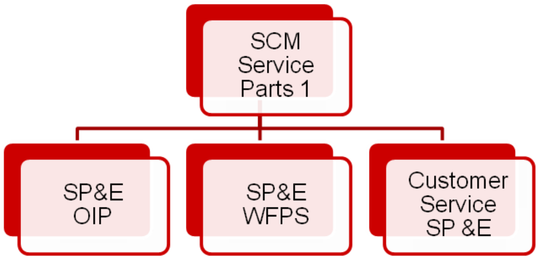

Figure 1.2: Organizational chart of SCM Service Parts 1

2 Spare parts distribution network in the current situation

The distribution network that is used by Océ for the distribution of spare parts around the world is described in this chapter.

2.1 Distribution network

The distribution network for spare parts of Océ can be found inFigure 2.1 (only regular replenishments are included). The Corporate Supply Center (CSC) of the department SCM Service Parts 1 is the most upstream location in the service supply chain of Océ. The CSC is located in Venlo and serves as a central warehouse from which the spare parts are distributed through the service supply chain. The next echelon in the network consists of six Regional Sales Headquarters (RSHQ's). These RSHQ's are located in the USA, Singapore, Australia, China, Korea and Japan. From the RSHQ's the spare parts flow to the Field Stock Locations either directly or indirectly via a National warehouse. The use of the RSHQ's originates from the merger between Océ and Canon. Canon has restricted Océ to use the RSHQ's in their distribution network. An exception to this is the European network. Due to complications with the IT, it is not possible that the European network is not served from the system operated by Océ. For this reason, the choice has been made not to use the Canon warehouse for Europe, but to keep serving the Field Stock Locations in Europe directly from the CSC in Venlo.

The Field Stock Locations consist of Quick Response Stocks (QRS), Car Stocks and some stock points at the customer's site. These stocks serve as stocks from which technicians in the field can quickly get spare parts in order to serve the customers of Océ machines as soon as possible in case a failure has occurred. For some spare parts, that have a high demand rate for example, inventory is kept in cars of technicians or for some customers even at the customer's site. Having a part available in a Car Stock or QRS prevents from a 'second visit due to parts'. With a 'second visit due to parts' it is meant that a technician cannot fix a machine that is down, because the required spare part is not available. This causes longer downtime of the machine which is very expensive. Also the technician has to come to the customer one more time, which causes extra costs. When a failure at a customer occurs, the technicians can take a spare part from their Car Stock or the stock at the customer and replace it with the failed part. The cars of technicians are not large enough to carry every part that is possibly needed. Therefore other spare parts are stored at Quick Response Stocks, which are small warehouses close to customer sites. In some countries the spare parts flow via a National warehouse to the Field Stock Locations.

Apart from the distribution network Océ also supplies dealers with spare parts. This is always done from the RSHQ's. From the CSC some OEM-partners are served.

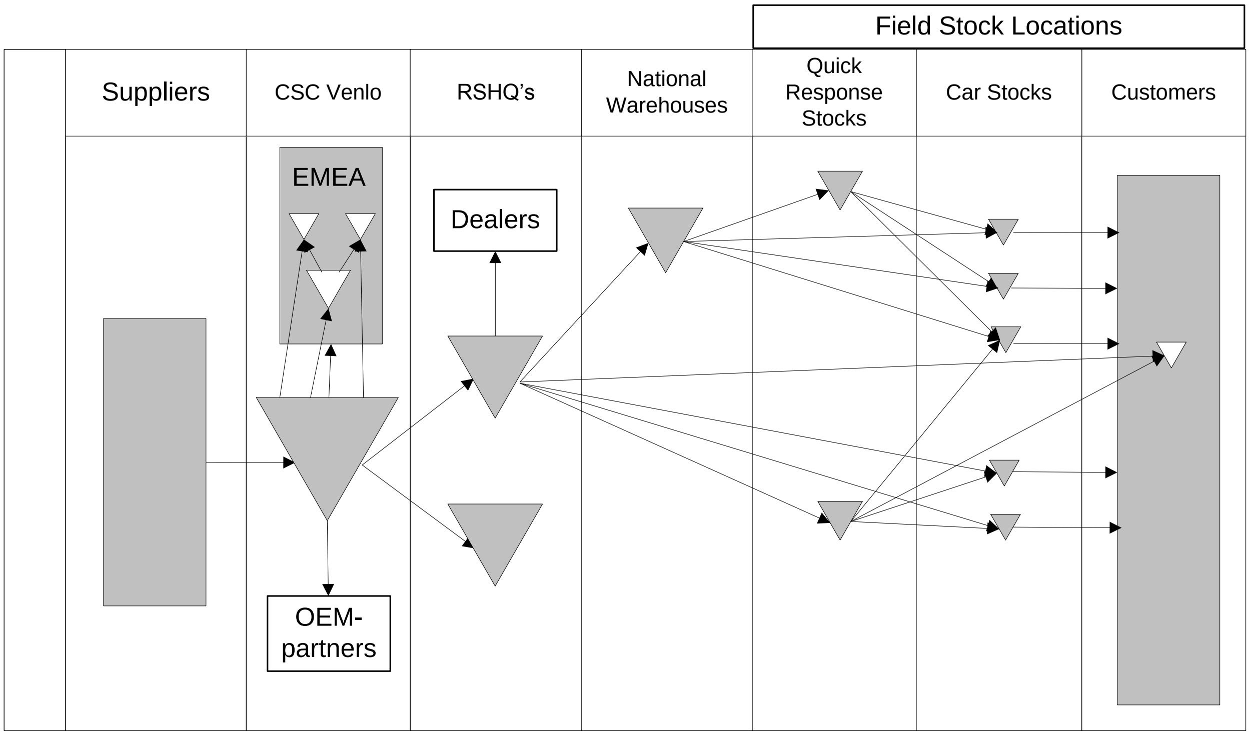

Figure 2.1: The distribution network for spare parts of Océ (regular replenishment streams only)

2.2 *Order process*

The current order process is the following: when demand at the customer's site arises, demand can be fulfilled from the Field Stock Locations, which all follow a base-stock policy for every item (i.e.: every single demand immediately causes a replenishment order). The National Warehouses, RSHQ's and the CSC place regular replenishment orders at their supplying location once a certain reorder level is reached. This can only be done at review moments (e.g.: once per week for an RSHQ). Sometimes demand cannot be fulfilled directly, because the demanded item is not available in both the Car Stock and the QRS. If this is the case, an emergency order is placed at the RSHQ (or National Warehouse) which is supplier for the demanding location. If the part is not available at that location either, an emergency request for the part is placed at the CSC Venlo. Océ does not use emergency shipments directly from the suppliers to the customers. Besides the emergency requests that originate directly from a demand for a spare part, National Warehouses can also request for an emergency shipment from the RSHQ or CSC and RSHQ's can request for an emergency shipment from the CSC. For shipments from the CSC to the RSHQ's, Océ uses three transportation modes: by sea, by air or by express (which is faster than air).

At the CSC, regular replenishment orders that are placed before a certain time (which differs per RSHQ) are shipped according to a fixed and agreed upon timetable. Some of the emergency orders that are placed before another determined point in time are put together with the regular replenishment order and are also shipped at the same day; other emergency orders are sent by express and are shipped separately. At the moment, between 30% and 50% of the orders from the Field Stock Locations are emergency requests. In Appendix A, all possible inbound and outbound flows for each location are summarized.

2.3 Current inventory control

For inventory control at the CSC Océ uses a method called XYZ. This is an ABC-classification method that uses three dimensions: price, demand and frequency. On the dimensions price and demand a part can be valued high, medium or low. The logic behind this classification is based on the system approach. The department SCM Spare Parts 1 operates an aggregate fill rate target of 97%. For parts with a different profile, different target service levels are set such that the aggregate fill rate of 97% is met. In practice this means that low valued fast-movers are controlled with a target fill rate of 99.5%, such that high valued slow-movers can be controlled with a target fill rate of only 90% to achieve the 97% aggregated over all the items. On the dimension frequency a differentiation is made between regularly and irregularly demanded items. Items that are demanded regularly are controlled with the use of forecasts, whereas irregularly demanded items are controlled with reorder points. An extensive explanation of this classification method is given in Appendix B. The XYZ-classification is done in Excel and then the results are uploaded to the SAP settings.

2.4 Cost structure

The objective of the research is to minimize the total spare parts costs for the distribution network. Océ identifies several different cost factors that are part of these total costs. These are:

- Transportation costs
- Inventory holding costs
- Warehousing costs
- Ordering costs

In this chapter these cost factors and their drivers are described.

2.4.1 Transportation costs

The transportation costs are very complex, since there are different agreements with all of the used transporters. For air and sea transport from the CSC to the RSHQ's the concept FOB/FCA Port of Departure applies. This means that the CSC is responsible for the transportation costs from their warehouse until the port of departure; from that point on the transport falls under the responsibility of the RSHQ. A graphical representation of the division of responsibilities of the transports via air or sea from the CSC to the RSHQ's can be found in Figure 2.2.

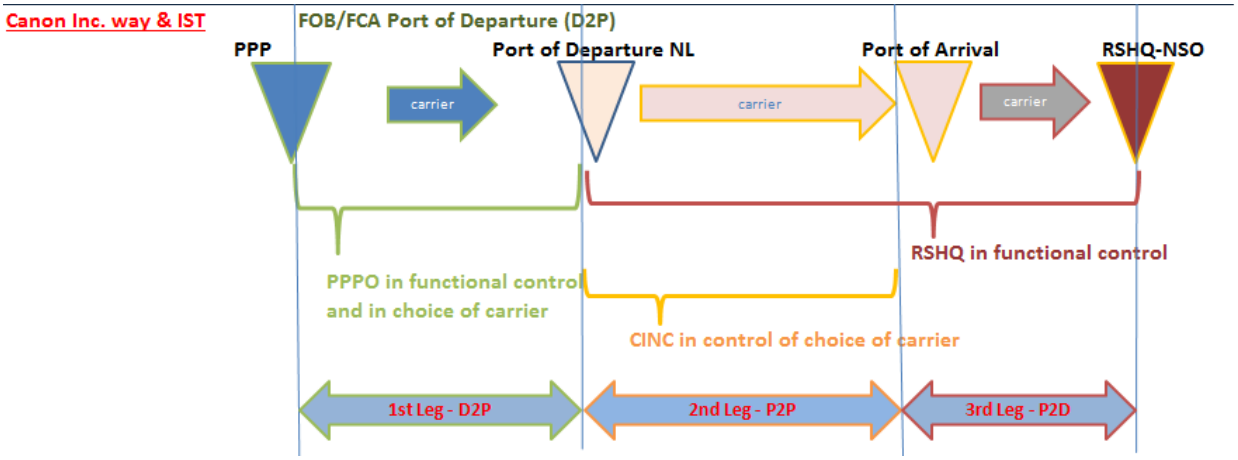

Figure 2.2: Division of responsibilities of transports from CSC (PPP) to RSHQ's

For express shipments FOB/FCA Collect is applied, which means that the RSHQ is responsible for the total transportation costs from Venlo to the RSHQ's. As a result of these concepts Océ only has detailed insight in a small part of the transportation costs. For the total costs of transportation from the CSC in Venlo to the RSHQ's, Océ is only able to use estimates based on the experience of knowledgeable employees. To this end, an interview with Ben Laenen has been taken. Ben Laenen is Manager Transport & Purchasing Logistics at Océ in Venlo. This interview has led to the estimates of the transportation costs from the CSC in Venlo to the RSHQ's that are given below.

Sea shipments

For sea shipments Océ uses 40-feet containers in about 85% of the cases. For the rest of the shipments most of the times 20-feet containers are used and sometimes 40-feet high cube containers are used. For the analysis of the transportation costs only 40-feet and 20-feet containers are considered, because the 40-feet high cube containers are only used occasionally. Estimates of the costs and transportation times from Venlo to the RSHQ's are given in Table 2.1.

Shipment to	Transportation time	Costs for 20-feet	Costs for 40-feet
CUSA	25 days	€2200	€3000
CCN	33 days	€1100	€1500
CSPL	28 days	€1100	€1500
CMJ	37 days	€2200	€3000
C Oceania	40 days	€2800	€3500
CKBS	40 days	€2800	€3500

Table 2.1: Transportation costs and transportation times for sea transport per full container per region

The transportation times that are given in Table 2.1 do not include the time that is necessary for picking, packing and transportation to and from the port. For these processes a total time of 17 days is used as a standard.

Based on the interview it is estimated that the utilization of the containers is only 35%. The choice for using full containers anyway is made by Canon and cannot be changed now by Océ. The utilization can be used to determine an average cost per m^3 for sea shipments. The average costs for sea transport per m^3 are given in Table 2.2 below.

Shipment to	Average costs per m3 20-feet	Average costs per m3 40-feet	Average costs per m3
CUSA	€ 190	€ 128	€ 137
CCN	€ 95	€ 64	€ 69
CSPL	€ 95	€ 64	€ 69
CMJ	€ 190	€ 128	€ 137
C Oceania	€ 242	€ 149	€ 163
CKBS	€ 242	€ 149	€ 163

Table 2.2: Average transportation costs for sea transport per m^3 per region

Air shipments

For regular air shipments a single cost rate worldwide is used, because the prices are fluctuating a lot. The transportation time for air shipments from the CSC Venlo to an RSHQ is 5 working days, but with picking, packing and transportation to and from the airport 14 days are used as standard lead time. The costs are estimated to be €4,50 per kg. from door to door (fuel and security costs are included). For voluminous goods a minimum price equal to the price of 167 kg. is applied by the air transporters.

Express shipments

For express shipments the transportation time is 3-4 days door-to-door. The costs are paid per shipment and are €50 if the shipment is smaller than 70 kg. The fill rate of emergency demand can be used to determine the average number of items per day that are shipped to the RSHQ’s. This average number can be used to translate the costs per shipment into costs for shipping an item.

2.4.2 Inventory holding costs

Several costs are accounted for the inventories held by Océ. In general these can be split up in two parts: a fixed part accounted per time period and a variable part, which is included in the gross price for a part.

The costs per time period consist of the costs for financing the inventory, which is held on stock. If a part is kept on stock, Océ must fund this part. For this funding, cost of capital is accounted. In general, there are two types of funding: equity and debt. The equity of a company consists of the shares for which dividends are paid. These dividends are the cost of capital for equity. The debts of a company consist mainly of many different types of liabilities such as loans and bonds. Interest is paid for these liabilities, which can be seen as the cost of capital for debts. Since the ratio between equity and liabilities does not have to be equal, the weighted average cost of capital (WACC) is generally used as a rate for holding inventory.

Another important part of the holding costs per time period is caused by the risk of obsolescence. In general, spare parts have a higher risk of being obsolete than other items or parts, since the demand pattern is very unpredictable and at the end of service date the demand stops entirely. For this reason the rate that is used for accounting the holding costs depends on the time left to the end of service. The rates per ESV-class (i.e.: time until the end of service date) are given in Table 2.3. For parts in the regular phase of the life cycle (ESV>24 months), the weighted average is calculated as a rate that is used in this assignment: this equals 13%. Together with the cost of capital an estimate of 20% per year is used as a holding cost rate. It should be kept in mind that these costs not only apply for inventories at the warehouses, but also for inventories in transit.

ESV (in months)	%
0-12	100
12-24	97
24-36	39
36-48	37
48-60	8
60-72	8
72-84	2

Table 2.3: Holding cost rate for risk of obsolescence per ESV-class (based on average inventory levels per ESV class in Q4 of 2013)

The variable cost part of the holding costs consists of many other costs that are made for keeping a part on stock. At Océ, these costs are included in the gross price for a part, so the details will not be examined here. Only the most important cost factors are described shortly in a list:

- Warehousing costs: the costs of using a certain amount of space for holding the inventory.
- Packaging material costs: the parts are repackaged in the warehouse, which costs money.
- Personnel costs: several people have to work and get paid for holding a part on stock.
- Transport costs: sometimes space is scarce in the warehouse, for which more space needs to be rented; then the parts also need to be transported to this other location.
- Overhead costs: all other expenses of operating a business.

2.4.3 Warehousing and ordering costs

The warehousing costs consist of many small parts, such as picking and packing. In general they can be categorized into inbound, outbound and storage costs. Océ translates all of these costs in costs per order line and the warehouse manager operates a target of €2,50 per order line. Because these costs are quite low and are mostly related to the optimal batch size (which is out of scope), the warehousing costs are left out of scope of the assignment.

The ordering costs are also relatively small costs that affect the optimal batch size, so the ordering costs are left out of scope as well.

2.5 Conclusion

In this chapter the current operations in the service supply chain have been described. The important characteristics of Océ's service supply chain are listed below:

- Multi-item problem
- Two-echelon system
- Two demand streams at the RSHQ's:
    - Regular replenishment orders (with backordering)
    - Emergency requests (with emergency shipments from the CSC)
- Four demand streams at the CSC (with backordering for every stream):
    - Regular replenishment orders of the RSHQ's
    - Emergency requests from the RSHQ's
    - Regular replenishment orders of the European network
    - Emergency requests from the European network
- Two possible transportation modes from the CSC to the RSHQ's:
    - Sea shipments
    - Air shipments
- Unknown demand distributions
- Periodic review at the RSHQ's of 1 week
- Continuous review at the CSC
- Single-unit ordering possible at the RSHQ's
- Aggregate fill rate constraint per demand stream
- Cost factors:
    - Holding costs
    - Transport costs
    - Penalty costs (additional costs for emergency shipments)

3 Problem definition

In the first section of this chapter, the current situation after the merger with Canon, with the use of the RSHQ's is analyzed. After that a problem statement is formulated.

3.1 Implications of using RSHQ's

Canon has restricted Océ to use the RSHQ's for the distribution of their spare parts. At the CSC this has some operational implications, which are discussed in this section.

A very influential implication of the inclusion of the RSHQ's in the service supply chain of Océ is that the nature of the orders that arrive at the CSC has changed. In the past, most of the orders that arrived were placed by the Field Stock Locations, which means that these were orders of one part only. The inventory control policies that are operated by Océ at the CSC are designed to minimize the total network costs in this situation. In the current situation, however, the orders that arrive at the CSC are mainly regular replenishment orders of the RSHQ's, which are orders of a larger batch size. This means that the inventory control policy that was previously used may not be suitable anymore for the current situation in which the demand pattern is different.

Besides the order process, the echelon structure of the inventory planning has changed. With this the addition of the layer of RSHQ's is meant. Before the merger with Canon, Océ used a regional supply centre in the USA and one in Singapore, so for these regions this echelon was already present. This echelon is now consisting of six warehouses instead of two.

Another implication of the use of the RSHQ's is that Océ has lost the control of the downstream inventory policies. Currently, the RSHQ's operate their own inventory control policies, which are not transparent to the spare parts planning department of Océ. This causes that Océ is not able to anticipate enough on orders coming from the RSHQ's. Furthermore, Océ does not know whether the inventory control policies operated by the RSHQ's are the right ones to minimize costs.

3.2 Problem statement

As mentioned above the adaptation of the service supply chain of Océ to the constraint of Canon to make use of the RSHQ's has some implications for Océ. These lead to the following problem statement:

'The inventory control policy, which is operated by Océ and the RSHQ's in order to minimize total network costs, and its optimization are not well suited to the distribution network that is used. On top of that, Océ is not in control of the inventories downstream of the CSC.'

A start to the solution of the problem has already been made by execution of the 'RSHQ Planning Project'. The aim of this project is to regain control of the inventory planning of the RSHQ's by Océ. The outcome of this project is that the integrated planning will make a proposition for the order size; the RSHQ's can then decide to make an order of minimally 0 units to 110% of the proposed quantity for every order line. Since these decisions are already agreed upon and regaining control of the inventory planning even further downstream is not feasible at the moment, getting in control of the inventories downstream of the RSHQ’s is not covered by this Master’s Thesis research. Therefore the problem statement that will be used for this Master’s Thesis is the following:

‘The inventory control policy, which is operated by Océ and the RSHQ’s in order to minimize total network costs, and its optimization, are not well suited to the distribution network that is used.’

3.3 Project objective

The objective of the Master’s Thesis project is to solve the problem stated above. This will be done by means of a tool that can be used to control the inventory of spare parts in the distribution network of Océ at both the CSC and the RSHQ’s. The tool should optimize the inventory control such that the total costs in the spare parts distribution network are minimized, while the target service levels for the customers are met. So the project objective is defined:

Develop a multi-item, multi-echelon inventory control policy for the CSC and the RHSQ’s in order to minimize total costs against given service level constraints and implement this in a tool.

3.4 Scope

This paragraph describes the scope of the Master’s Thesis assignment. This is done from different viewpoints.

3.4.1 Network

As already mentioned in 3.2 a project is currently running to gain control over the spare part inventories at the RSHQ’s. At the moment it is clear that the outcome of this project will be that the integrated planning will make a proposition for the order size. Therefore in the scope of the assignment the RSHQ’s receive order proposals from the CSC.

The suppliers’ inventories are out of scope, as well as the inventories downstream of the RSHQ’s. Inclusion of these locations in the model would be more close to optimal, but it is not feasible that the inventories of these locations will be controlled centrally in the near future. Regarding the European network the choice is made to leave the downstream planning out of scope as well, because this planning is the responsibility of Canon Europe. A representation of the scope with regards to the distribution network is given in Figure 3.1.

Since this scope is chosen for the project, the ‘customers’ are: (i) the National Warehouses, the Field Stock Locations and the dealers, that order at the RSHQ’s outside Europe, (ii) and the National Warehouses and the Field Stock Locations and the dealers, that order directly at the CSC Venlo. Incoming orders can be classified in regular replenishment orders and emergency requests. The target service level that is operated by Océ is an aggregate fill rate per RSHQ. A differentiation may be specified between the regular replenishment orders and the emergency requests.

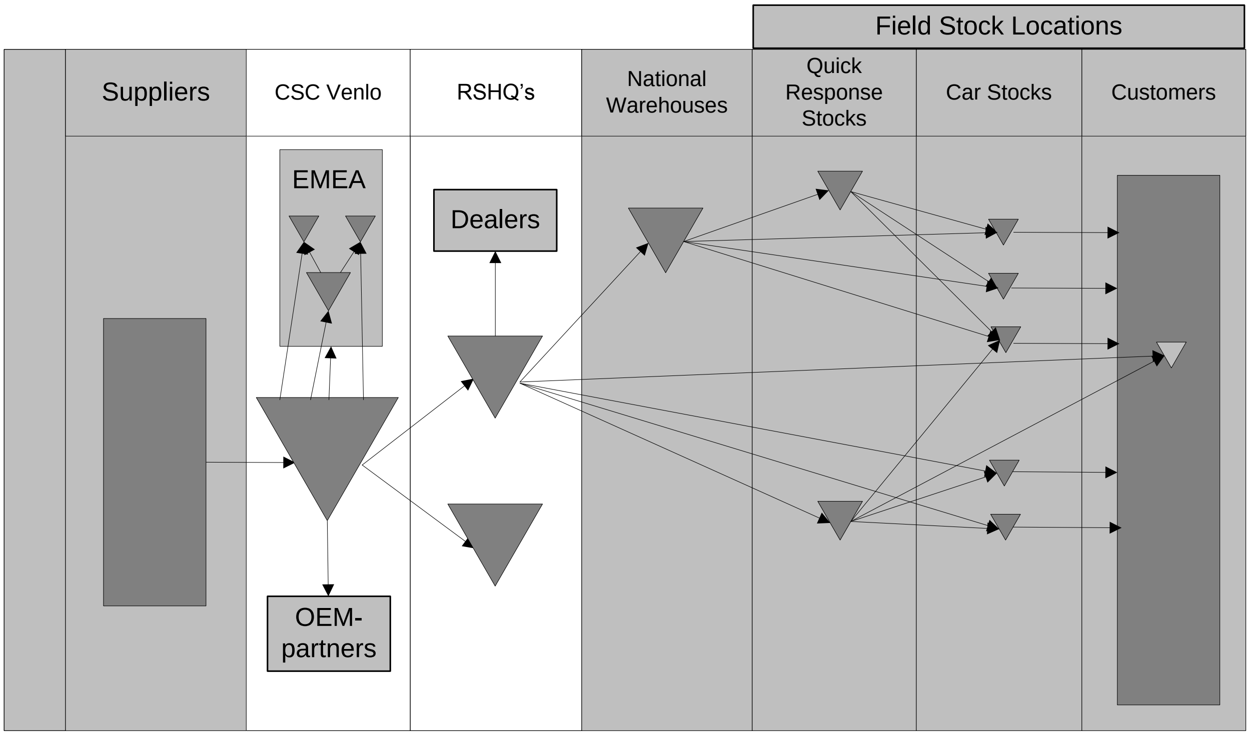

Figure 3.1: Distribution network for spare parts of Océ (the white part is within scope of the assignment)

3.4.2 Items

In spare parts planning, a differentiation can be made between critical parts and non-critical parts. A critical part is a part that causes downtime of a system if it fails. Currently the same control policy is used for critical parts and non-critical parts that are demanded more than three times per year. For the design of the new inventory control policy only critical parts are in scope of this assignment, since the reason for having a well-performing spare parts distribution network is to be able to react quickly in case of system downtime. The system can also be used for non-critical parts, but the effects of this inclusion are not examined in this thesis.

Besides the differentiation between critical and non-critical parts, a distinction can be made between regular parts and parts that are in the phasing-in or phasing-out phase. Parts that are in the phasing-in phase are parts that are new to the system of which the demand pattern is increasing towards a steady state. Parts that are in the phasing-out phase are parts that are in the end phase of their usage. For these parts the demands are declining. The scope of this assignment is on regular parts only, because the model that will be developed needs to perform well in the steady state. Phasing-in and phasing-out parts need manual attention and are therefore left out of scope.

Another differentiation that can be made is between Océ-parts and other spare parts that are located in the Océ spare parts warehouses. These other parts are for instance parts for Canon-products, but since this assignment is aimed for Océ and its products these other parts are out of the scope.

3.5 Methodology

In order to make sure that the project objective is reached, a structural approach with three phases has been followed. These phases are, in sequential order, conceptual design phase, detailed design phase and integration phase (Bertrand, 2013).

In the conceptual design phase a set of functional requirements is specified. It is described which available model will be used make the design. In the case that a single model is not feasible, more than one model will be selected to use as building blocks for the design. Then it is also described how they will be connected to each other.

The next phase is the detailed design phase. In this phase the inventory control policy is designed in detail. One part of this policy is the model that represents the supply chain, which is developed in detail as well as its optimization. All decision variables and parameters are specified and procedures for order handling and making emergency requests are developed in this phase. The detailed design ensures that the functional requirements specified in the conceptual design are met.

During the integration phase the detailed design is translated in a tool. The collected data is used, after data preparation, for testing and validation of the tool.

3.6 Thesis outline

In chapter 4 the related scientific literature is reviewed in order to find one or more models that can be useful for the design of the inventory control tool for spare parts of Océ. In chapter 5 the conceptual design is presented. A set of functional requirements for the design is given and the design parameters are determined. This chapter ends with the design choices on a conceptual level. Chapter 0 presents the detailed design. In this chapter the mathematical models that are used in the design are explained in detail. It further shows the solution procedure to find the optimal parameter settings at the different locations. Some practical complexities have arisen, which are handled in chapter 0. In chapter 0 the results of this research are presented; the test results are shown and a sensitivity analysis is carried out in order to measure how sensitive the output is to changes in input variables. Chapter 9 deals with implementation issues. In chapter 0 this thesis is finalized with conclusions and recommendations to Océ.

4 Related literature

In this chapter a review is given on the existing literature about the inventory planning and control of spare parts that is related to this design. The following specific characteristics of the problem at Océ have been identified in chapter 2:

- Multi-item problem,
- Two-echelon system,
- Two heterogeneous demand classes at the RSHQ's:
  - With emergency shipments for one class and;
  - With backordering for the other class,
- Four homogeneous demand classes at the CSC:
  - With backordering for all classes,
- Two possible transportation modes from the CSC to the RSHQ's,
- General demand distributions,
- Periodic review at the RSHQ's,
- Continuous review at the CSC,
- Aggregate fill rate constraint per demand stream.

Although many different topics and combinations of topics have already been studied about spare parts, there are also some combinations of topics that have not been studied yet, or no practically applicable solution method has been developed yet. A model with all of the abovementioned characteristics has not been developed so far. For that reason this chapter searches for the models that fit the problem of Océ the best.

4.1 Spare parts multi-echelon distribution systems

Several multi-echelon distribution systems have been developed and described in the existing literature. Clark and Scarf (1960) have developed a method to determine optimal base-stock levels in serial systems and indicate that it can be used as an approximate method for distribution systems. Sherbrooke (1968) developed METRIC as an easy-to-use method for determining base stock levels in multi-echelon systems based on the assumption that the stochastic lead time, consisting of shipment time and waiting time caused by backorders, can be replaced by its mean. Graves (1985) used another assumption which causes his method to be more close to optimality than the METRIC approximation. Graves' assumption is that the shipment times from the central warehouse to the local warehouses can be replaced by their means. Gallego, Özer and Zipkin (2007) present a very simple heuristic to approximately analyze a two-echelon distribution system with stochastic demand and continuous review for one item. The Restriction-Decomposition heuristic consists of three subheuristics and selects the best of the three solutions. With three subheuristics the system can be analyzed with the use of simple news-vendor problems, making this method very easy to use.

The models discussed so far do not incorporate emergency shipments, which is an important characteristic of Océ's spare parts distribution. One of the models that use emergency shipments is the one used by Alfredsson and Verrijdt (1999). In this model, a demand is preferred to be served directly from the local warehouse. Otherwise it can be sent from another local warehouse, which is called a lateral transshipment. If this is not possible, it can be sent directly to the customer from the central warehouse and in the situation that this is not possible either, demand can be satisfied by a direct shipment from a supplier. Alfredsson and Verrijdt use a two-step approach where they first calculate the fractions of the demand satisfied directly from the supplier and directly from the warehouse; secondly they estimate the fractions of the demand satisfied from other local warehouses and directly from stock. The problem with this approach is again the computational power, since it requires a numerical solution of two-dimensional Markov processes. Özkan, van Houtum and Serin (2011) have developed an approximate evaluation method for a similar two-echelon inventory system with emergency shipments from the central warehouse. Their evaluation method is efficient and their model fits quite closely to the distribution network of Océ, but it lacks a differentiation between customer classes and it does not use periodic review. Another drawback of this model to the design for Océ is that it is not a multi-item model.

Other recent work by Song and Zipkin (2009) uses pipeline information to determine which supply source should be used. An emergency shipment is chosen if a threshold value is reached for the number of orders in transit with an expected residual lead time that is higher than the emergency lead time. This method is originally developed by Moinzadeh and Schmidt (1991). Song and Zipkin have developed performance evaluation and optimization tools for different ordering policies. The main drawbacks of this model for Océ are that it is a single-location model, without customer differentiation and that it is a single item model. Furthermore it uses continuous review.

The above methods all follow the item approach, which means that they optimize the parameters for every item separately. In practice Océ operates an aggregate service level for their spare parts, because the machines' uptime is important for the customers, regardless of what causes a possible machine down. Methods that use an aggregate service level in their optimization follow the system approach.

The multi-item single-location model, which is the most simple model based on the system approach, is described in detail by Basten and van Houtum (2014) based upon the past literature. This is not a distribution network model though. Wong, Kranenburg, van Houtum and Cattrysse (2007) present several solution methods for a two-echelon distribution system based on the system approach. They recommend using a so called Greedy-algorithm with the use of the approximate evaluation method of Graves (1985). Topan and Bayindir (2012) use a multi-item approach in a two-echelon system with batch ordering in the central warehouse under compound Poisson demand. This system is quite closely related to the situation at Océ, besides that there are no emergency orders and customer classes in the model.

4.2 Single-location models with customer differentiation

All of the abovementioned do not have more than one demand class. In the distribution network at Océ, there are at least two demand classes at every location. This section discusses models that use customer differentiation. To the best of our knowledge there is no multi-echelon model available in literature that is close to the network of Océ, so only single-location models are discussed here.

Veinott (1965) was the first to study on a differentiation in demand classes. He introduced the use of critical levels to determine an optimal inventory policy in a single-item, single-location situation. This concept of critical levels has been used by many other later researchers in various model settings. Möllering and Thonemann (2008) show a critical level policy with optimal backorder clearing and periodic review in a single-location model with two-demand classes. Their model does not assume a Poisson distribution, but any demand distribution can be applied. They have derived an optimal solution algorithm for this problem, which is however not efficient enough for practical use in case that lead times or demands are high. Cohen, Kleindorfer and Lee (1988) and Tempelmeier (2006) both use periodic review and a general demand distribution in combination with a critical level policy for a single-item, single-location problem as well. These models are based on the assumption that the pipeline is empty at the moment that an order is placed. At Océ generally more than one order is outstanding at the same moment, for which reason this assumption is not valid in the case of Océ. Deshpande, Cohen and Donohue (2003) also use a critical level in a single-item, single-location system with backordering if a part is not available. Their method is based on 'threshold clearing' of backorders, which is used as an approximation for the optimal 'priority clearing' mechanism. This method is efficient and the approximation is close, but its drawback is that it is a single-item model with continuous review and backordering for all classes. At the CSC Océ uses continuous review and backordering, but at the RSHQ's periodic review is applied and emergency shipments are used for one of the demand classes.

Kranenburg and van Houtum (2007) have developed three efficient heuristic algorithms that can be used to optimize base stock levels and critical levels in a single-echelon, multi-item model with multiple demand classes and emergency shipments. In another article they showed that this algorithm can be used to make substantial cost savings (Kranenburg & van Houtum, 2008). The drawback of these models in comparison to the system that is used by Océ is that they use emergency shipments for all demand classes, whereas at Océ there is backordering taking place for regular replenishment orders and emergency shipments for emergency requests.

A model that does make this distinction is the model by Enders, Adan, Scheller-Wolf and van Houtum (2014). This model is a single-item, single-echelon model with two "heterogeneous" customer classes, where emergency shipments are used for the high priority class and backordering for the low priority class. A critical level is used to reserve stock for the high priority demand class. Enders et al. (2014) have developed an efficient solution approach to find the optimal base-stock level and critical level. This model is not a multi-item model and does not use periodic review though.

4.3 Comparison between the models and Océ

At the top of this chapter, the specific characteristics of the service supply chain of Océ in scope were listed. From the literature review it can be concluded that there is no model available in literature that fits perfectly to Océ. Therefore the models that come close are compared with Océ's distribution network in Table 4.1. The two-echelon models do not fit very close to Océ's practice with regards to the other characteristics. Not one of them has customer differentiation or periodic review included. The model of Özkan et al. (2011) has the closest fit with regards to the emergency shipments that they include. The models of Wong et al. (2007) and Topan et al. (2012) are multi-item models, but they do not include emergency shipments. The models with periodic review and customer differentiation are both single-item, single-location models with customer differentiation that do not assume a Poisson process. They do only not include emergency shipments. The drawback of the model of Möllering and Thonemann (2008) is the computation time, which increases significantly as the lead time or the expected demand increases. The model of Tempelmeier (2006) is based on the assumption that the pipeline is empty, which is invalid in Océ's network. The main strength of the model of Kranenburg and van Houtum (2007) compared to the others with regards to the network of Océ is that it combines a multi-item model with emergency shipments and customer differentiation. The models of Deshpande et al. (2003) and Enders et al. (2014) also differentiate between customers, but these are single-item models. The model of Enders et al. (2014) has a close fit to the RSHQ's, since this model uses emergency shipments only for the priority class.

Model	Single-item/ multi-item	Single-location/ multi-echelon	Customer differentiation	Emergency shipments	Periodic review	Demand distribution
Océ network	Multi-item	Two-echelon	Yes	Yes, for one of the classes (At RSHQ), No (At CSC)	Yes (At RSHQ), No (At CSC)	General
Gallego et al. (2007)	Single-item	Two-echelon	No	No	No	Poisson
Özkan et al. (2011)	Single-item	Two-echelon	No	Yes	No	Poisson
Wong et al. (2007)	Multi-item	Two-echelon	No	No	No	Poisson
Topan et al. (2012)	Multi-item	Two-echelon	No	No	No	Compound Poisson
Möllering et al. (2008)	Single-item	Single-location	Yes	No	Yes	General
Tempelmeier (2006)	Single-item	Single-location	Yes	No	Yes	General
Deshpande et al. (2003)	Single-item	Single-location	Yes	No	No	Poisson
Kranenburg et al. (2007)	Multi-item	Single-location	Yes	Yes	No	Poisson
Enders et al. (2014)	Single-item	Single-location	Yes	Yes, for one of the classes	No	Poisson

Table 4.1: Comparison between scientific models and the Océ spare parts distribution network

4.4 Conclusion

No model is available that fits perfectly to the spare parts distribution network of Océ. In this chapter a review was given of the models that share characteristics with Océ's network. These models can be used as building blocks for the design of the inventory control concept for the spare parts distribution of Océ. In chapter 5, the models are selected that will use as building blocks based on the characteristics that they have. In chapter 0, these models are adapted and reformulated to fit to Océ such that they make a good representation of the distribution network.

5 Conceptual design

The first part of the methodology for design used in this research is the conceptual design. This is the first step in the approach presented by Bertrand (2013), who outlines an approach for designing logistic control systems. With this approach, the functional requirements are the objectives of the system to be designed and the constraints. These requirements form a constraining basis for the design. After the functional requirements are specified in 5.1, the design parameters are determined in 0. These design parameters form the design space and in order to reduce this design space the design parameters are organized hierarchically. To reduce the complexity of the design in which typically many interdependencies exist, Bertrand (2013) proposes to use independent modules. These modules are units in a larger system that are independent of each other, but work together to achieve the functional requirements. The conceptual design itself, choices with regards to the design parameters, is presented in 5.3.

5.1 Functional requirements

The functional requirements are based on the project objective, the problem characteristics and the scope of the assignment. The project objective was defined in section 3.3 as follows:

Develop a multi-item, multi-echelon inventory control policy for the CSC and the RHSQ's in order to minimize total costs against given service level constraints and implement this in a tool.

Three requirements follow from this design objective: *minimize total costs*, meet the *given service level constraints* and *a tool* should be developed. In this section the functional requirements of the design are determined more specifically based upon these requirements.

The total costs should be minimized according to the project objective. However, in the literature review in chapter 4 it is concluded that there is no model available that optimizes the inventory control policy in a network such as the one of Océ. Since the network is so complex and the optimal inventory control policy is not known, the minimal costs are not known either. This implies that the objective to minimize the costs cannot be tested. Therefore the first constraint is refined as follows: *the inventory control system should be cost efficient*.

In order to be able to meet the given service level constraints these need to be specified. The service level constraints are important, because they make sure that the distribution network downstream the RSHQ's can be operated effectively. For the EMEA network, including Field Stock Locations and National Warehouses, Océ currently operates an aggregate fill rate target of 97%. This target has proven for Océ to be an efficient target to be reliable enough for the downstream network. Therefore it has been agreed with the manager of the department SCM Service Parts 1 that this target is used as a constraint for the supplying location of the Field Stock Locations and National Warehouses. This means that the RSHQ's all have an *aggregate fill rate constraint of 97%* for the demand from the Field Stock Locations and National Warehouses. For the CSC the same aggregate fill rate constraint of 97% is specified for demand from the EMEA-network, including Field Stock Locations and National Warehouses. Besides the Field Stock Locations, the RSHQ's serve dealers and the CSC serves OEM-partners. The dealers are treated equally to the 'own' Field Stock Locations by the RSHQ's, so the same aggregate fill rate constraint of 97% is specified for the dealers. The same applies at the CSC for the OEM-partners, which means that the aggregate fill rate constraint of 97% is also specified for the OEM-partners at the CSC.

For the tool that should be developed, functional requirements are specified as well. These functional requirements are related to using the tool in practice. In order that the tool will actually be used in practice, it should be easy to use. This means that the user interface should be understandable for the logistic engineers of Océ. It should be clear how the tool should be used. Furthermore it should be easy to run the model with the tool, which is among others related to the ease of setting up a model run and to the computation time of the model, which should not be high. With regards to the future use of the tool the maintainability of the model is important. The coding should be written such that the model can be maintained whenever this is necessary. So overall the functional requirements for the tool are specified as follows: *the tool to be designed should be easy to understand, run and maintain*.

In Table 5.1 the functional requirements for the design of the inventory control system for spare parts of Océ are summarized.

Functional Requirements	**Description**
FR1	The inventory control system should be **cost efficient**.
FR2	1. An **aggregate fill rate** constraint of **97%** should be met for the demand from the Field Stock Locations and National Warehouses at each RSHQ.
	2. An **aggregate fill rate** constraint of **97%** should be met for the demand from the dealers at each RSHQ.
	3. An **aggregate fill rate** constraint of **97%** should be met for the demand from the (EMEA-)Field Stock Locations and National Warehouses at the CSC.
	4. An **aggregate fill rate** constraint of **97%** should be met for the demand from the OEM-partners at the CSC.
FR3	The tool to be designed should be **easy to understand, run and maintain**.

Table 5.1: Functional requirements of the design

5.2 Design parameters

Design parameters can be seen as knobs to tune the design. Bertrand (2013) mentions hierarchy in the design parameters. At the higher level, decisions need to be taken about the type of control policies and whether locations or processes need to be integrated or decomposed. At the lower level, typical design parameters are reorder points, batch sizes and so forth. For this design the following design parameters are specified:

DP1. System approach/ item approach/ ABC-classification:
  a) Classification variables (control characteristics)
  b) Number of classes

In optimization of logistic control systems a differentiation can be made between the item approach and the system approach. The item approach uses an optimization for every item independently, with the aggregate service level as a target for every item. The system approach is based on the assumption that the target service level does not need to be reached for every item as long as it is reached on aggregate.

This results in a different service level for every item. An intermediate approach based on classes, an ABC-classification, is also possible. Such an approach is similar to the system approach, apart from that the items are not all operating a different service level, but the items are classified based on similarities between them and the service levels are different between classes, but the same within classes. If an ABC-classification is chosen, the number of classes and the variables on which the classes are based have to be determined.

DP2. Decomposition of locations/ models:

The optimization of inventory control policies of multi-echelon systems is generally very complex. When multiple demand classes or transport modes are considered, the complexity even increases. A method to decrease the complexity is decomposing the control in different modules. In the case of this design, a choice should be made on the decomposition of the CSC and the RSHQ's: integrate or decompose. In case of integration both echelons will be described and optimized with the use of one single model. In case of decomposition there are separate models for both echelons and the output of one model serves as input for the other model.

DP3. Type of inventory policy:

a) Mechanisms
b) Reorder points/ S-levels
c) Critical levels
d) Batch sizes

With regards to the inventory policy, the higher hierarchical design choice is on the type of inventory policy. There are many types of inventory policies possible, such as base-stock policies, (R,s,Q)-policies, critical level policies and many other policies. Also combinations of policies are possible. As a consequence of the policy which is chosen different lower hierarchical design parameters apply. Mechanisms, such as rules for backordering or the choice between transportation modes, need to be designed and parameters, such as reorder points, critical levels or batch sizes may also need to be designed dependent on the chosen inventory policy type.

5.3 Design: control policies and modeling

In this chapter the design choices of the conceptual design are presented. Parts of the conceptual design are the chosen inventory control policies and the choice for the models to be used for optimization of these policies. The design parameters described in 5.2 form the basis of the design.

5.3.1 System approach/ item approach/ ABC-classification

It is generally known that the system approach dominates the item approach with regards to both total costs and service level performance (e.g.: Topan and Bayindir, 2012). With regards to the ease of use, the item approach is better than the system approach though. In order to mimic the performance effects of the system approach, while using models based on the item approach, an ABC-classification can be used. This is currently done by Océ as described in section 2.3. Since Océ is already familiar with using an ABC classification and such a method comes closer to the system approach than the item approach, the item approach is ruled out from the design.

In the literature review in chapter 4 several candidate models have been described. Unfortunately the characteristics of these models are such that the choice between a multi-item and a single-item model is correlated with the choice between a single-location and a two-echelon model and the fit to the other system characteristics. As can be seen from Table 4.1, the model of Topan and Bayindir (2012) is a multi-item, two-echelon model with compound Poisson demand. This model has no customer differentiation or emergency shipments though.

The model of Kranenburg and van Houtum (2007) is the only multi-item model that was described in the literature review that includes customer differentiation. This model uses emergency shipments for all of the customer classes (homogeneous customer classes), whereas in the system of Océ at the RSHQ's emergency shipments are used only for emergency demand (heterogeneous customer classes). This is only described in the model of Enders et al. (2014), which is a single-item model that can be used with an ABC-classification. The models of Kranenburg and van Houtum (2007) and Enders et al. (2014) are both single-location models, so the tradeoff is between using the system approach or heterogeneous customer classes.

From literature it is known that the system approach is optimal (e.g.: Topan and Bayindir, 2012), so it dominates the ABC-classification with regards to cost minimization and service level maximization. The ABC-classification is much easier to understand and operate though. Furthermore it is known that Océ is only willing to use the system approach if the performance gap with the ABC-classification is high. The performance gap is not known in a multi-echelon system such as the service supply chain of Océ, without working out both approaches in detail. For a single-echelon system it is known that the performance gap between an ABC-classification and the system approach is relatively small (van Wingerden, 2014).

System approach Model of Kranenburg & van Houtum (2007)	**ABC-classification** Model of Enders et al. (2014)
Single-location model	Single-location model
Optimal	Suboptimal (performance gap small for single-location)
Difficult to understand	Easy to understand
Not preferred by Océ	Preferred by Océ
Homogeneous customer classes	Heterogeneous customer classes

Table 5.2: Comparison for tradeoff between the system approach and an ABC-classification

In Table 5.2 the differences between the system approach and the ABC-classification are summarized. The only point that weighs in favor of the system approach is that the system approach is known to be optimal. Since the performance gap between the system approach and an ABC-classification is small for a single-location system, it is assumed that the performance gap at a single-location is small between the two approaches. Both models are single-location models and all of the other factors weigh in favor for the ABC-classification. Therefore the design choice is made to use an ABC-classification. With this choice the functional requirements can be met, since an ABC-classification is assumed to be efficient and easy to use and maintain. This is confirmed by the current practice of Océ.

Due to the choice for the ABC-classification, the variables to base the classification on should be determined as well. The following are chosen:

- Average demand
- Part price
- Frequency

These are the same variables that are used currently (See 2.3). Using demand and price has a strong impact on the total relevant costs and performance and frequency is kept as well, because Océ uses a forecast, which is only useful for relative frequently demanded items.

Van Wingerden (2014) showed that with three classes on the dimensions average demand and part price, the performance gap at a single-location with the system approach is already relatively small. Therefore the number of classes is chosen to be kept similar to the current situation, meaning that for average demand and part price there are three possible values (high, medium and low) and for frequency there are two possibilities (frequent and infrequent).

5.3.2 Decomposition

The complete system that is operated by Océ is extremely complex compared to the models available in literature. As already concluded in chapter 4, there is no model available that incorporates customer differentiation, emergency shipments, periodic review and general distributed demand in a multi-echelon model. The model of Özkan et al. (2011) is the two-echelon model with emergency shipments that fits the closest to the distribution system of Océ. This model does not use customer differentiation, but this characteristic is a very important one for Océ. Since there are no multi-echelon models available in the literature that share many of the characteristics of Océ's distribution network, the choice is made to decompose the system into smaller parts.

Since the network consists of two echelons, the only choice for decomposing is to decompose into single modules for both echelons. This means that there are two modules: Control Unit 1 represents the inventory control of the CSC; Control Unit 2 represents the inventory control of the RSHQ's. For both modules a model is selected in section 5.3.3.

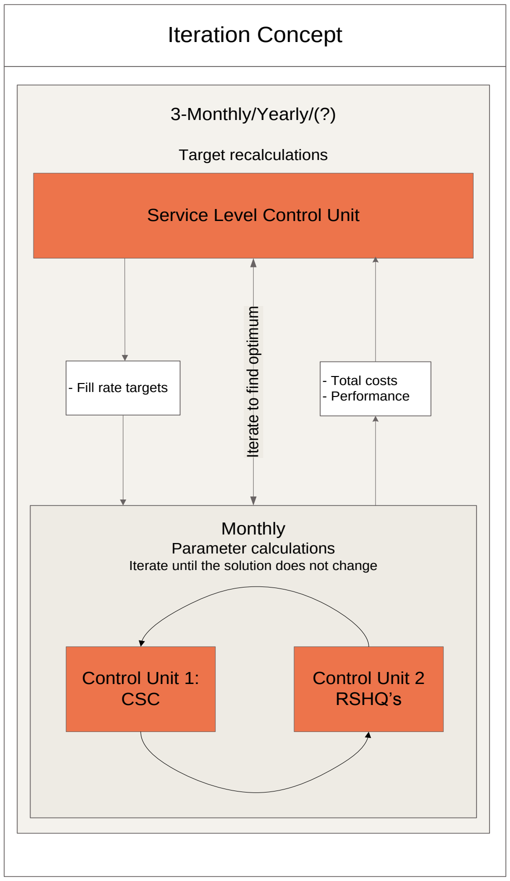

Figure 5.1: Iteration concept

An extra control unit which is called Service Level Control Unit is used to determine which input values are used for Control Units 1 and 2. The Control Units 1 and 2 are designed such that they can operate independently of each other, when the output of other Control Unit is known. Since all Control Units have inputs from other Control Units, it is necessary to use an iteration to find the best solution. The iteration concept can be found in Figure 5.1.

The mechanism is the following:

1. The Service Level Control unit searches for optimal fill rate targets per class
2. In every iteration:
    a. Determine optimal parameter settings for Control Unit 2
    b. Determine optimal parameter settings for Control Unit 1
    c. Iterate over step a. and b. until the solution does not change
    d. Output total costs and performance
3. Iterate over step 1. and 2. until no improvements for the fill rate targets per class are found

5.3.3 Type of inventory policies

The two echelons have different characteristics, so different control policies may be used for the two echelons. The policies that are chosen and their interdependencies are described in this paragraph.

5.3.3.1 RSHQ inventory policy

The following characteristics and cost aspects have been identified that influence the choice of the inventory policy at the RSHQ's:

- Two inbound transportation modes (sea and air)
- Periodic review for sea and air shipments with a review period of 1 week
- Receive single-unit demands
- Two types of demand: regular replenishment and emergency request from the downstream service supply chain and from dealers
- Possibility to request for an emergency shipment at the CSC (lost sales for RSHQ)

These characteristics lead to the formulation of the following variable policy parameters (the explanation of this follows on page 25):

- One order-up-to level (S)
- One regular transportation mode used per item (sea or air)
- One critical level for emergency requests (c)

The mechanisms that are used are the following:

- Serve both types of demand as long as the inventory on hand is larger than c
- Serve only emergency requests when the inventory on hand is lower than or equal to c
- Backorder regular replenishment orders when the inventory on hand is lower than or equal to c
- Deliver backorders as soon as inventory on hand increases above c

- Request for an emergency shipment from the CSC for satisfying an emergency request when there is no inventory on hand on a continuous basis
- At a review moment, if the inventory position is below the order-up-to level, place an order that increases the inventory position up to the order-up-to level.

The reasoning for choosing the policy with one order-up-to level (S) and a choice for the transportation mode to be used is that this takes into account the different possibilities for transportation, but does not increase complexity too much. Although especially for cheaper items it may be reasonable to use larger batches to prevent from unnecessary many orders, using such a fixed batch size would increase the complexity of the model enormously. Therefore a fixed batch size is not used and the fixed costs per order line are left out of scope. Batch sizes could be determined separately from the model to be designed. The difference between periodic and continuous review originates from the ordering system and agreed upon fixed timetables that are used by Océ. Note that the express shipment mode (see 2.2) is left out of scope, since this shipment mode is normally not used. Only in case of emergencies an express shipment will be requested; this decision will be left over to the planner.

The differences between the two types of demands lead to the critical level policy. Emergency requests are originating directly from customer demand, whereas regular replenishment orders originate from demand of downstream locations (to fill their stocks). Since serving the customer is the ultimate goal of the service supply chain, the emergency requests have a higher priority than the regular replenishment orders. Therefore the choice is made to use a critical level to reserve stock for serving emergency requests when the on hand inventory level is running low. Furthermore a different mechanism is used in case that a demand cannot be fulfilled. Emergency requests are then passed on to the CSC as an emergency shipment request, because the customer demand is important to be fulfilled as soon as possible. For regular replenishment orders backordering is used, because these orders do not originate directly from customer demand, there is no need for making extra costs with an emergency shipment.

To determine the parameters of Control Unit 2 the model of Enders et al. (2014) will be used in an adapted way. The reason for this choice is that this model fits the best to the characteristics of the inventory control at the RSHQ’s (see 4.3). The model of Enders et al. (2014) uses a different treatment of two customer classes in the same way as in the actual situation. This is the main reason for choosing this model as a building block. Yet, there are several differences between the model of Enders et al. (2014) and the characteristics of the actual situation. These differences are represented in Table 5.3.

Alternatives are models with periodic review and generally distributed demand. As already described in chapter 4, the models of Tempelmeier (2006) and Cohen et al. (1988) make use of an invalid assumption. The other candidate model with periodic review is the model of Möllering and Thonemann (2008). Using this model has been examined, but this turned out to cause very long calculation times with lead times as long as the ones of Océ. Therefore this model is also not chosen. In chapter 0, a solution to the differences between the model of Enders et al. (2014) and the distribution system of Océ is given.

Actual situation	Model of Enders et al. (2014)
Periodic review for air and sea shipments	Continuous review
Two different transportation sources	One transportation source
Deterministic lead time + expected waiting time	Exponentially distributed lead time
No penalty costs for backorders	Penalty costs for backorders
Higher transportation costs for lost sales	Penalty costs for lost sales
Target fill rates	No target fill rates
General demand distribution	Poisson demand process

Table 5.3: Differences between the actual situation at the RSHQ's and the model of Enders et al. (2014)

5.3.3.2 CSC inventory policy

The following characteristics and cost aspects have been identified that influence the choice of the inventory policy at the CSC:

- One inbound transportation mode per item (choice is not in scope of the assignment)
- Continuous review
- Mixture of batched and single-unit demand
- Four types of demand:
    - Regular replenishment orders and emergency requests for RSHQ's
    - Regular replenishment orders and emergency requests for the European network and OEM-partners
- Fixed costs per order line (left out of scope)

These characteristics lead to the formulation of the following variable policy parameters:

- One order-up-to level (S)
- One critical level for differentiation between demand types (C)

The mechanisms that are used are the following:

- Serve orders for regular shipments of the RSHQ's as long as the inventory on hand is larger than the critical level
- Serve only emergency shipment requests of RSHQ's and demands from the European network when the inventory on hand is lower than or equal to the critical level
- Backorder orders for regular shipments of the RSHQ's when the inventory on hand is lower than or equal to the critical level
- Backorder emergency shipment requests of RSHQ's and demands from the European network when there is no inventory on hand
- Deliver backorders for regular shipments of the RSHQ's as soon as inventory on hand increases above the critical level
- Deliver backorders for emergency shipment requests of RSHQ's and demands from the European network as soon as there is inventory on hand
- Continuously, if there is demand, place an order at the supplier that increases the inventory position to the order-up-to level.

The reason for using the critical level is that in this way inventory is reserved for more urgent orders in case that the on hand inventory level is running low. It would even be possible to use multiple critical levels for differentiation between the different demand streams. This causes however a quite complex mechanism, which would not be easy to operate in practice. Therefore the choice is made to bundle the demands from the European network with the emergency requests of the RSHQ's. The fixed costs per order line are left out of scope for the same reason as they are left out of scope at the RSHQ's. Backordering is used in all cases, because emergency shipments from suppliers are left out of scope of this assignment.

The parameters of Control Unit 1 will be determined with the model of Deshpande et al. (2003). This is a single-location model that uses two customer classes as well, but with backordering for both demand classes (see chapter 4). Again there are some differences between the model and the actual situation. These are represented in Table 5.4.

The only major difference between the actual situation and the model of Deshpande et al. (2003) is the demand distribution. In 4.3 it can be found that all of the models with generally distributed demand have periodic review as well. These cannot be used at the CSC for the same reasons that they are not useful for the RSHQ's. Therefore we are restricted to use a model that uses a Poisson process.

Actual situation	Model of Deshpande et al. (2003)
General demand process	Poisson demand process
Both single-unit and batched demand	Single-unit demand
Four demand streams (combined into two classes)	Two demand classes
Target fill rates	No target fill rates
No penalty costs	Penalty costs
No setup costs	Setup costs
Order-up-to level → fixed batch size = 1	Reorder level with fixed batch size ≥ 1
"Priority backorder clearing"	"Threshold backorder clearing"

Table 5.4: Differences between the actual situation at the CSC and the model of Deshpande et al. (2003)

5.3.3.3 Service level control

For the Service Level Control Unit, the choice is made to use an ABC-classification as mentioned in 5.3.1. There are different ways of determining the correct service levels as input for the models. Van Wingerden (2014) has used a greedy approach to iteratively find the right target service levels per class in a single echelon system with one customer class. Such an approach is, to the best of my knowledge, not yet developed for a two-echelon system with heterogeneous customer classes as the one at Océ. Another way to do the job is to manually search for a good 'set up' of the system. This approach is less accurate, but also a lot less complex. For this reason the choice is made to use a manual analysis on the target service levels per target to find a good solution. The results of this analysis are presented further on in 8.4.1. Since an optimization approach for a system like this is not yet developed, it is not possible to compare the manual search with a more advanced approach. This could be a topic for a follow-up project.

5.3.3.4 Interdependencies

There are several interdependencies between the different Control Units. These can best be explained in terms of inputs and outputs of the Control Units. Note that a solution is defined as the set of all target fill rates and backorder performance levels per item. The Control Units and their interdependencies are represented graphically in Figure 5.2.

Service Level Control Unit

Input for the Service Level Control Unit is the set of target aggregate fill rates for the total system (FR2). The Service Level Control Unit generates solutions that potentially improve the performance of the system. In the first step it generates an initial solution. As mentioned above, the generation of potential solutions will be done manually. The output of the Service Level Control Unit is a set of solutions with:

- Target fill rates per item and per order stream (i.e.: different order types from the RSHQ's) for the inventory at the CSC
- Target fill rates per item and per order stream (i.e.: regular replenishment orders/ emergency requests) for the inventory at the RSHQ's. For every RSHQ the same fill rates are used.

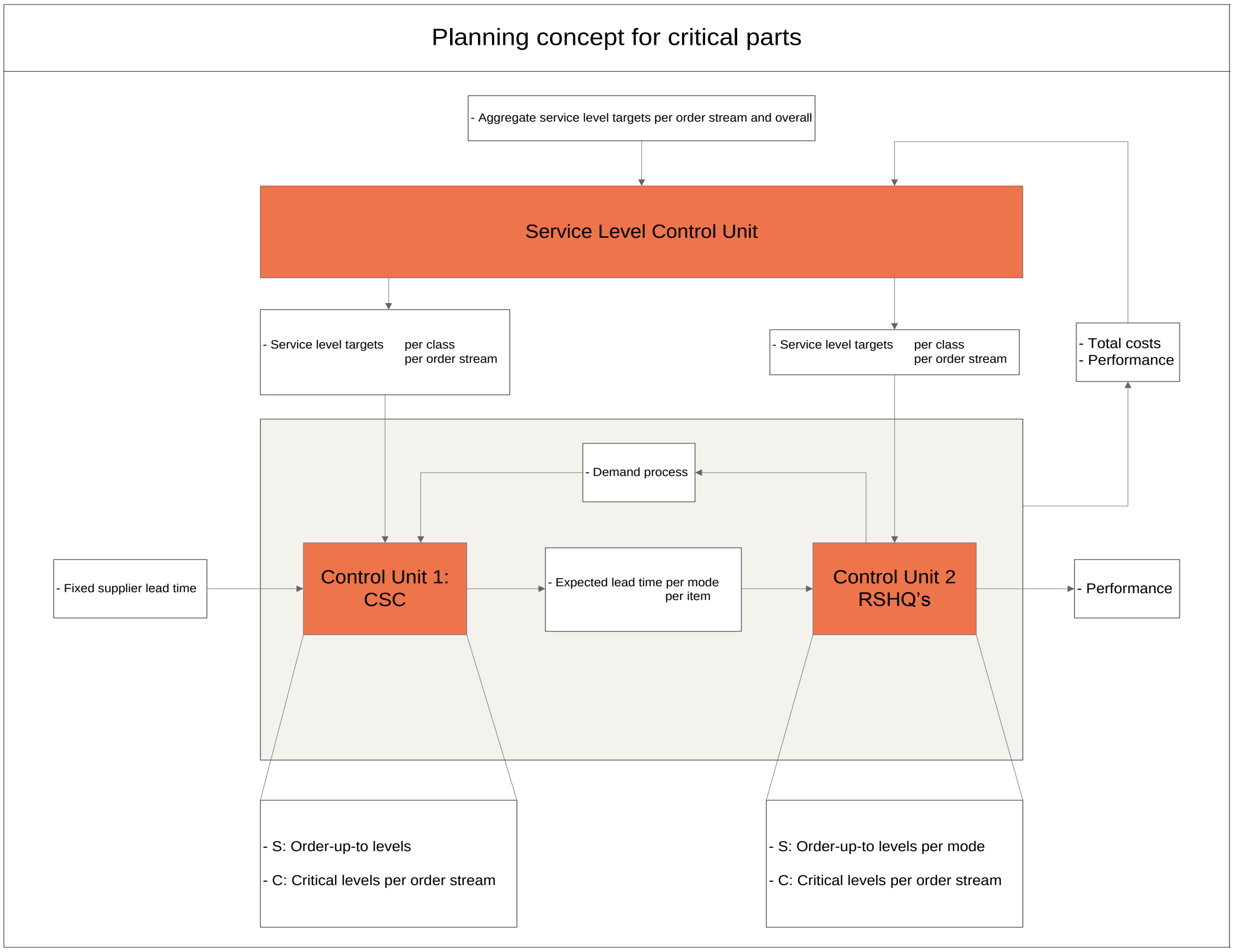

Figure 5.2: Planning concept including interdependencies between Control Units

Control Unit 2

Since the parameter settings for all items that are determined by Control Unit 2 are independent per item, these Control Units will be designed such that they can be run for a single item. Input for Control Units 2 is the following output of the Service Level Control Unit and the Control Unit 1:

- Target fill rate of the item per order stream for the inventory at the RSHQ's
- Expected waiting time at the CSC for the item for the replenishment order stream

The function of the Control Unit 2 is to define the optimal parameter settings for the inventory control of the specific item at the RSHQ's. These are the parameters that are pointed out in 5.3.3.1. The mean lead times from the CSC to the RSHQ consist of a fixed transportation time plus an expected waiting time for backorders at the CSC, which is an output value of Control Unit 1. Using this output value makes sure that the parameters of Control Unit 2 can be determined independently of the parameters of Control Unit 1. The outputs of the Control Unit 2 are:

- A demand process of the item per order stream of the RSHQ's at the CSC (including emergency shipments)
- Costs for this item made at the RSHQ
- Expected fill rate of the item per order stream

Control Unit 1

Similar to Control Unit 2 this Control Unit can also be run for a single item. The inputs that are needed by Control Unit 1 are outputs from the Service Level Control Unit and the Control Unit 2:

- Target fill rates for the item per order stream for the inventory at the CSC
- Target expected waiting times for the item per order stream at the CSC
- The demand process of the item per order stream (output of Control Unit 2)

The function of Control Unit 1 is to define the optimal parameter settings for the inventory control of the specific item at the CSC. These are the parameters that are pointed out in 5.3.3.2. The outputs of Control Unit 1 are:

- Costs for this item made at the CSC
- Expected fill rate of the item per order stream
- Expected waiting time for the item for the replenishment order stream

Iterations

In section 5.3.2 the iteration concept between the Control Units was described. The interdependency between the Control Units 1 and 2 is formed by the expected waiting time at the CSC and the demand process of the RSHQ's to the CSC. When the target fill rates are specified, the starting point for the iteration is a maximum of the expected waiting time at the CSC equal to the lead time to the CSC. Then Control Units 1 and 2 are iteratively used until no changes in the solution occur.

6 Detailed design

In this chapter the inventory policies and the models to determine their parameter values are described in detail for the CSC and the RSHQ's. For both locations the differences between the used model and practice are described and the solutions to this. Furthermore a detailed description of the models is given to understand them.

6.1 *Control Unit 1: CSC*

The inventory control policy at the CSC will be an (S, c)-policy with backordering for both demand classes. To determine the order-up-to levels and critical levels the model of Deshpande et al. (2003) will be used. This model uses a policy called (Q, r, K)-policy, where Q denotes the fixed batch size, r denotes the reorder point and K denotes the critical level (which is c in our case); also with backordering for both demand classes. The notation used for Control Unit 1 is summarized in Table 6.1.

Variable	Description
r	Reorder point
K	Critical level
Q	Fixed batch size ($= 1$ in this case)
i	Customer class ($i = 1$ for emergency demand from RSHQ's and direct demand, $i = 2$ for regular demand)
λ_i	Demand rate of class i
λ	Total demand rate
τ	Deterministic lead time
μ	Average demand during the lead time
α_i	Fraction of total demand formed by demand of class i
$p(x; \lambda\tau)$	Poisson probability of having in total x demand arrivals during the lead time τ
$b(\alpha_i; n; n_i)$	Binomial probability that there are exactly n_i class i demands from a total demand stream of n customers
h	Holding cost rate
$C^T(r, K)$	Expected total costs per time unit with parameter values r and K
$H^T(r, K)$	Expected holding costs per time unit with parameter values r and K
$B_i(r, K)$	Expected backorder level for class i demands with parameter values r and K
$W_i^T(r, K)$	Expected waiting time for class i demands with parameter values r and K
$\beta_i^T(r, K)$	Expected fill rate for class i demands with parameter values r and K
$A_i(r, K)$	Expected fraction of time out of stock for class i demands with parameter values r and K
β_i^{min}	Target (minimum) fill rate for class i demands
$C_{LB}^T(r, K)$	Lower bound of the expected total costs per time unit with parameter values r and K
$\hat{C}_{LB}^T(r)$	Lower bound of the expected total costs per time unit with a fixed r
$\hat{C}^{T*}(r)$	Minimal expected total costs per time unit for a fixed r
$\tilde{C}^{T*}(K)$	Minimal expected total costs per time unit for a fixed r for $K \leq K$ (i.e.: up to K)

Table 6.1: Notation of the model used for the optimization of Control Unit 1

6.1.1 *Difference between policies*

The most obvious difference between the policy of Deshpande et al. (2003) and the inventory control policy that will be modeled for the CSC is the batch size. Deshpande et al. (2003) use a fixed batch size and a reorder point, whereas in the actual situation an order-up-to level will be used. Since the fixed costs per order line, such as warehousing costs and ordering costs, are left out of scope there would be no reason to use a batch size larger than 1 in case that the demand follows from a Poisson process with single-unit demands. Therefore the (S, c)-policy of the actual situation is in fact equivalent to a (Q, r, K)-policy with $Q = 1$, $r = S - 1$ and $K = c$. This actually simplifies the calculations compared to a fixed batch size that may have any value.

Another difference between the policies is the backorder clearing mechanism. The backorder clearing mechanism at the CSC will be as follows: first clear the backorders of the highest priority class and only clear backorders of the lowest priority class when the on-hand inventory is above the critical level. This mechanism, called "priority clearing" by Deshpande et al. (2003), is known to minimize costs. The mechanism that is used in the model of Deshpande et al. (2003) is called "threshold clearing": backorders that arrive before the inventory position reaches a certain threshold are cleared at a FCFS basis, backorders that arrive afterwards are served similar to the "priority clearing". For a more detailed description of the "threshold clearing" mechanism reference is made to the original article of Deshpande et al. (2003). The reason for using this clearing mechanism is that this simplifies the analysis very much. In the article the difference in performance between the two backorder clearing mechanisms is examined and found to be very small, only when the difference between the customer classes is very large they found a cost difference of 3%. For the other cases they found no difference. The difference between the two customer classes is not expected to be so large as in the single case where a difference was found. Therefore the "threshold clearing" mechanism of Deshpande et al. (2003) can be used to determine the policy parameters after which "priority clearing" can be used in practice.

6.1.2 *Difference between demand processes*

The model of Deshpande et al. (2003) assumes that orders arrive following from a Poisson process. In 5.3.3.2 it was discussed that the available models with generally distributed demand cannot be used in this case. Therefore the assumption that the demand follows a Poisson process is tested in Appendix C. It turns out that for many parts the demand distribution does not follow a Poisson process. The reason for this is possibly that the locations downstream use inventory control policies that do not yield a Poisson ordering process. The fact that the demand does not follow a Poisson process complicates the design enormously, which cannot be solved easily by adapting the model or selecting another model. Therefore a Poisson demand process assumption is used for the design anyway, after which a solution to this complexity is given in chapter 0.

6.1.3 *Cost function*

The optimization problem used by Deshpande et al. (2003) is as follows:

$$\begin{aligned} \min_{Q,r,K,K \le r+Q} \quad & C^T(Q,r,K), \\ \text{where} \quad & C^T(Q,r,K) = S^T(Q,r,K) + H^T(Q,r,K) + Z^T(Q,r,K). \end{aligned} \tag{1}$$

The cost function consists of three parts: $S^T(Q,r,K)$, which represents the setup costs, $H^T(Q,r,K)$, which represents the holding costs and $Z^T(Q,r,K)$, which represents the penalty costs. The superscripted T is used to make clear that the "threshold clearing" mechanism is used. In the actual situation we have only holding costs, $H^T(Q,r,K)$, and Q is always equal to 1, so the optimization problem may be reformulated into:

$$\begin{aligned} \min_{r,K,K\leq r+1} \quad & C^T(r,K), \\ \text{where} \quad & C^T(r,K) = H^T(r,K). \end{aligned} \tag{2}$$

The expression for the holding costs in Deshpande et al. (2003) is:

$$H^T(Q,r,K) = h\left\{\frac{(Q+1)}{2} + r - \mu + B_1(Q,r,K) + B_2(Q,r,K)\right\}. \tag{3}$$

In this equation h is the holding cost rate, μ is the average lead time demand, $B_1(Q,r,K)$ is the average number of backorders of class 1 demands and $B_2(Q,r,K)$ is the average number of backorders of class 2 demands. In the actual situation Q is always equal to 1 and we have no shortage costs and fixed ordering costs, so the expression for the costs becomes:

$$C^T(r,K) = H^T(r,K) = h\big(r + 1 - \mu + B_1(r,K) + B_2(r,K)\big). \tag{4}$$

6.1.4 Constraints

The model of Deshpande et al. (2003) uses no constraints. In the actual situation though, there are both fill rate and waiting time constraints for both demand classes. Let $\beta_i^T(r,K)$ denote the fill rate for demands of class i, then the optimization problem becomes:

$$\begin{aligned} \min_{r,K,K\leq r+1} \quad & C^T(r,K), \\ \text{where} \quad & C^T(r,K) = H^T(r,K), \\ s.t. \quad & \beta_i^T(r,K) \geq \beta_i^{min} \qquad for\ i \in \{1,2\}, \end{aligned} \tag{5}$$

6.1.5 Evaluation

Deshpande et al. (2003) have deducted a formula to determine the expected fraction of time the system is out of stock for class i. For the special case with $Q = 1$ that we have, this is:

$$A_i(r,K) = a_i(r+1,K), \tag{6}$$

where

$$a_1(y,K) = \sum_{x=y}^{\infty}\sum_{j=0}^{x-y} b(\alpha_1; x-y+K; K+j)p(x;\lambda\tau),$$

and

$$a_2(y,K) = \begin{cases} \sum_{x=y-K}^{\infty} p(x;\lambda\tau) & \text{if } K \leq y \\ 1 & \text{if } K > y \end{cases}.$$

In the functions above, y denotes the inventory position; $p(x;\lambda\tau)$ is the probability of having in total x demand arrivals during the lead time τ; $\alpha_i = \frac{\lambda_i}{\lambda}$ denotes the probability of an arrival being class i; $b(\alpha_i;n;n_i) = \frac{n!}{n_i!(n-n_i)!}\alpha_i^{n_i}(1-\alpha_i)^{n-n_i}$ is the probability that there are exactly n_i class i demands from a demand stream of n customers. Expression (6) can be used to calculate the fill rate of class i:

$$\beta_i^T(r,K) = 1 - A_i(r,K). \tag{7}$$

To determine the average waiting time per class the expected number of backorders per class can be used. This expected number of backorders can be calculated in a similar way to (6):

$$B_i(r,K) = b_i(r+1,K), \tag{8}$$

where

$$b_1(y,K) = \sum_{x=y}^{\infty}\sum_{j=0}^{x-y} jb(\alpha_1;x-y+K;K+j)p(x;\lambda\tau),$$

and

$$b_2(y,K) = \begin{cases} \sum_{x=y-k}^{\infty} \alpha_2(x-y+K)p(x;\lambda\tau) & \text{if } K \leq y \\ \lambda_2\tau + \alpha_2(K-y) & \text{if } K > y \end{cases}.$$

The average waiting time per class can be calculated simply now according to Little's law:

$$W_i^T(r,K) = \frac{B_i(r,K)}{\lambda_i}. \tag{9}$$

The deduction of these formulas is quite complex; for detailed information about this, reference is made to Deshpande et al. (2003). The infinite sums need to be truncated. This is done by summing up until the corresponding probability is smaller than 10^{-6}. The effect of this truncation can be examined in a sensitivity analysis by comparing the truncation value to the computation time and the difference in costs.

6.1.6 Solution procedure

The idea behind the solution procedure is to search efficiently for the optimal solution by starting from the constraints and only evaluate the entire policy in case the constraints are satisfied. Without the constraints, the solution procedure would be as follows: started is from the lowest possible $r = -1$ and $K = 0$. Then two iterations are used: a 'main iteration' in which r is increased one unit at a time and a 'sub iteration' in which r is fixed and K is increased one unit at a time. Deshpande et al. (2003) show with their Lemma 5 that $b_i(y,K)$ is convex in y for a fixed K and convex in K for a fixed y. This implies via deduction that the cost function $C^T(r,K)$ is convex in r for a fixed K and convex in K for a fixed r. Therefore this solution procedure will find the optimal solution.

In order to make the solution procedure more efficient, a lower bound for the costs will be used. This method is similar to the one used by Enders et al. (2014). Using (4) the total costs of a certain (r, K)-policy, $C^T(r, K)$, can be bounded:

$$C^T(r, K) \geq C^T_{LB}(r, K) \coloneqq h\big(r + 1 - \mu + B_2(r, K)\big). \tag{10}$$

Let $\hat{C}^{T*}(r)$ denote the optimal cost for a fixed r. Then this can be bounded as follows using (4):

$$\hat{C}^{T*}(r) \geq \hat{C}^T_{LB}(r) \coloneqq h(r + 1 - \mu). \tag{11}$$

Only if the lower bound of the costs (11) of the policy with $r = r + 1$ is lower than the lowest costs found until then, the policies with $r = r + 1$ are evaluated by starting the sub iteration with initially $K = 0$. In every 'sub iteration', only if the lower bound of the costs (10) of the policy with $K = K + 1$ is lower than the lowest costs found until then in the 'sub iteration' ($\tilde{C}^{T*}(K)$), the policy with $K = K + 1$ is evaluated in detail. As soon as K is equal to r, or the lower bound (10) is not lower than the lowest found costs until then, the 'sub iteration' terminates and the 'main iteration' proceeds with $r = r + 1$ and $K = 0$. This iterative approach continues until the lower bound of the costs (11) is not lower than the lowest costs that are found already.

The fill rate constraints are included such that a policy is only evaluated if the fill rate constraints are met for this policy. In the 'main iteration', r is increased until the fill rate constraint for class 2 customers is met. If also the fill rate constraint for class 1 customers is met, the policy is evaluated and the 'sub iteration' is used until the fill rate constraint for class 2 customers is not met anymore. Then the 'main iteration' proceeds with increasing r with one unit. The logic behind this procedure is in line with Lemmas 1 and 2 of Deshpande et al. (2003), which confirm that the fill rate for class 2 customers is increasing in r and decreasing in K and the fill rate for class 1 customers is increasing in r and increasing in K. In Algorithm 6.1 the solution procedure can be found.

Algorithm 6.1: Optimize CSC $(\boldsymbol{r}, \boldsymbol{K})$-policy

```
input := $\beta_1^{min}; \beta_2^{min}; W_2^{max}; \lambda_1; \lambda_2; \tau; h$
$r \leftarrow -1$
$\hat{C}^{T*}(r) \leftarrow \infty$
while $\hat{C}^{T*}(r) > \hat{C}_{LB}^{T}(r+1)$
do
    $K \leftarrow 0$
    $\tilde{C}^{T*}(K) \leftarrow \infty$
    $\beta_2^T(r,K) \leftarrow Evaluate\beta_2(r,K)$
    $W_2^T(r,K) \leftarrow EvaluateW_2(r,K)$
    while $\beta_2^T(r,K) \geq \beta_2^{min}$ and $\tilde{C}^{T*}(K) > C_{LB}^{T}(r,K+1)$
    do
        $\beta_1^T(r,K) \leftarrow Evaluate\beta_1(r,K)$
        if $\beta_1^T(r,K) \geq \beta_1^{min}$
            then $C^T(r,K) \leftarrow EvaluatePolicy(r,K)$
            if $C^T(r,K) < \tilde{C}^{T*}(K)$
                then $\tilde{C}^{T*}(K) \leftarrow C^T(r,K)$
        $K \leftarrow K+1$
        $\beta_2^T(r,K) \leftarrow Evaluate\beta_2(r,K)$
        $W_2^T(r,K) \leftarrow EvaluateW_2(r,K)$
    if $\tilde{C}^{T*}(K) < \hat{C}^{T*}(r)$
        then $\hat{C}^{T*}(r) \leftarrow \tilde{C}^{T*}(K)$
    $r \leftarrow r+1$
output := $r, K, \beta_1^T(r,K); \beta_2^T(r,K); W_2^T(r,K); \hat{C}^{T*}(r)$
```

6.2 *Control Unit 2: RSHQ's*

The inventory control policy at the RSHQ's is an (S, c)-policy with emergency shipments for the priority demand class and backordering for the lower demand class. Furthermore a choice between sea- and air shipments is part of the inventory control policy at the RSHQ's. To determine the order-up-to levels and critical levels the model of Enders et al. (2014) will be used. This model uses a (S, c)-policy S denotes the base-stock level and c denotes the critical level; also with emergency shipment for the priority demand class and backordering for the lower demand class. The notation used for Control Unit 2 is summarized in Table 6.2.

6.2.1 *Difference between policies*

The most obvious difference between the policy of Enders et al. (2014) and the inventory control policy that will be modeled for the RSHQ's is the review period. Enders et al. use continuous review, whereas in the actual situation periodic review is exploited. The model of Enders et al. makes use of a two-dimensional Markov-chain. Demand arrivals follow a Poisson process and the lead times are exponentially distributed. This model cannot be adapted directly to a periodic review environment, so there is need to use an approximation.

Variable	Description
S	Order-up-to level
c	Critical level
R	Review period
L	Deterministic transportation time from CSC to RSHQ
i	Customer class ($i = 1$ for emergency demand, $i = 2$ for regular demand)
λ_i	Demand rate of class i
λ	Total demand rate
W	Expected waiting time at the CSC
μ^{-1}	Average lead time
h	Holding cost rate
c_t	Transportation costs per item for a regular shipment from the CSC to the RSHQ
c_t^{em}	Transportation costs per item via an emergency shipment from the CSC to the customer
$C(S, c)$	Expected total costs per time unit with parameter values S and c
$B(r, K)$	Expected backorder level for with parameter values S and c
$I(r, K)$	Expected on hand inventory level with parameter values S and c
$\beta_i(r, K)$	Expected fill rate for class i demands with parameter values S and c
β_i^{min}	Target (minimum) fill rate for class i demands
$\pi_{m,n}$	Steady state probability of the state with m items on hand and n backorders
$\boldsymbol{\pi}_n$	Vector of all steady state probabilities with n backorders
$\tilde{\pi}_{m,n}$	Auxiliary steady state probability of the state with m items on hand and n backorders (normalized with $\tilde{\pi}_{S,0} = 1$)
$\tilde{\boldsymbol{\pi}}_n$	Vector of all auxiliary steady state probabilities with n backorders
Q	Generator of Markov process
ℓ	Variable used for bounding
$C_{LB}(S, c)$	Lower bound of the expected total costs per time unit with parameter values S and c
$\hat{C}_{LB}(S)$	Lower bound of the expected total costs per time unit with a fixed S
$\hat{C}(S)$	Minimal expected total costs per time unit for a fixed S
$\tilde{C}^*(c)$	Minimal expected total costs per time unit for a fixed S for $c \leq c$ (i.e.: up to c)

Table 6.2: Notation of the model used for the optimization of Control Unit 2

If continuous review is used in the model, whereas it is periodic review in practice, this practical situation can be approximated by adapting the mean lead time. Suppose that a review period of R days will be used and the deterministic transportation time is L days, there is ample supply from the CSC and a base stock level is applied. For an arbitrary demand this means that the lead time follows a uniform distribution over $(L, L + R)$ with mean $\mu^{-1} = L + \frac{1}{2}R$. Besides the waiting time caused by the review period, there may be some waiting time caused by an out-of-stock situation at the CSC. Now let W denote the expected waiting time for the item at the CSC. The mean lead time now becomes $\mu^{-1} = L + \frac{1}{2}R + W$. Note that this expected waiting time is an output value of the model of the CSC. The performance of the model of Enders et al. (2014) is proven to be quite insensitive to lead time variability. This means that the lead time can be assumed to be exponential with a rate of μ, despite the fact that this assumption is not valid. The reason for assuming an exponential distribution is that this allows for the use of Markov chains, which is done by Enders et al. (2014).

Another difference is that the model of Enders et al. (2014) allows for the use of only one regular transport mode, whereas in scope of the project there are two possible transport modes: sea and air. The solution to this difference is to use the model twice, once with the lead time and corresponding costs of sea transportation and once with the lead time and costs of air shipments. The solution with the lowest costs is then chosen.

6.2.2 *Difference between demand processes*

Similar to the model of Deshpande et al. (2003), the model of Enders et al. (2014) assumes that orders arrive according to a Poisson process. This assumption is tested in Appendix C, where it is found that the assumption is not valid in this case. There is no useful model with a general demand distribution available in literature though (see chapter 4). The model of Enders et al. (2014) can also not be adapted to generally distributed demand, so for the RSHQ the assumption that the demand follows a Poisson process needs to be made as well. A solution to the problem that this assumption is not valid is given in chapter 0.

6.2.3 *Cost function*

The optimization problem used by Enders et al. (2014) is the following:

$$\begin{array}{rcl} \min\limits_{S,c} C(S,c) & = & \min\limits_{S,c} \{p_1\lambda_1\big(1-\beta_1(S,c)\big) + p_2\lambda_2\big(1-\beta_2(S,c)\big) + bB(S,c) + hI(S,c)\}, \\ s.t. & & c \le S, \\ & & s, C \in \mathbb{N}_0. \end{array} \tag{12}$$

The cost function consists of four parts: $p_1\lambda_1\big(1-\beta_1(S,c)\big)$, which represents the penalty costs for not satisfying demand of the highest priority class from on-hand inventory; $p_2\lambda_2\big(1-\beta_2(S,c)\big)$, which represents penalty costs for not satisfying demand of the lower priority class from on-hand inventory; $bB(S,c)$, which represents the penalty cost per time unit for having outstanding backorders and $hI(S,c)$, which represents the holding costs. In the actual situation there are only holding costs and transportation costs, so the optimization problem may be reformulated into:

$$\begin{array}{rcl} \min\limits_{S,c} C(S,c) & = & \min\limits_{S,c} \{c_t^{em}\lambda_1\big(1-\beta_1(S,c)\big) + c_t(\lambda_1\beta_1(S,c) + \lambda_2) + h\big(S - I(s,c)\big) + hI(S,c)\}, \\ s.t. & & c \le S, \\ & & s, C \in \mathbb{N}_0. \end{array} \tag{13}$$

Here c_t denotes the transportation costs for a regular shipment from the CSC to the RSHQ and c_t^{em} denotes the transportation costs for an emergency shipment from the CSC. $\beta_i(S,c)$ denotes the fill rate for demands of class i and $I(S,c)$ denotes the average on-hand inventory. Note that the holding costs for inventory in transit are also taken inside the cost function. The reason for this choice is that these costs may differ significantly between sea transport and air shipments.

6.2.4 *Constraints*

The model of Enders et al. (2014) uses no constraints. In the actual situation though, there are fill rate constraints for both demand classes and an aggregate fill rate constraint over both demand classes. The optimization problem then becomes:

$$
\begin{aligned}
\min_{S,c} C(S,c) \quad &= \quad \min_{S,c} \left\{ c_t^{em}\lambda_1\big(1-\beta_1(S,c)\big) + c_t(\lambda_1\beta_1(S,c)+\lambda_2) + h\big(S - I(s,c)\big) + hI(S,c) \right\}, \\
s.t. \quad & \quad \beta_i(S,c) \geq \beta_i^{min} \qquad\qquad for\ i \in \{1,2\}, \\
& \quad c \leq S, \\
& \quad s, C \in \mathbb{N}_0.
\end{aligned} \tag{14}
$$

6.2.5 Evaluation

For the evaluation of the problem Enders et al. (2014) make use of Markov chains with states (m,n), $m \in \mathbb{N}_0$ represents the number of items on hand and $n \in \mathbb{N}_0$ represents the number of outstanding backorders. Let $\pi_{m,n}$ denote the steady state probabilities of the Markov chain, now the following performance measures can be expressed in terms of $\pi_{m,n}$:

$$\beta_1(S,c) = 1 - \textstyle\sum_{n=0}^{\infty} \pi_{0,n}, \tag{15}$$

$$\beta_2(S,c) = \textstyle\sum_{m=c+1}^{S} \pi_{m,0}, \tag{16}$$

$$I(S,c) = \textstyle\sum_{m=1}^{S} m\pi_{m,0} + \sum_{m=1}^{c}\sum_{n=1}^{\infty} m\pi_{m,n}, \tag{17}$$

$$B(S,c) = \textstyle\sum_{m=0}^{c}\sum_{n=1}^{\infty} n\pi_{m,n}. \tag{18}$$

An efficient procedure to determine these performance measures is described in detail in Enders et al. (2014). The basis of their method is that the states are partitioned into *levels*. Level n consists of the following states:

$$
\begin{array}{ll}
\{(0,0),(1,0),\ldots,(c,0),\ldots,(S,0)\} & \text{for level } n = 0, \\
\{(0,n),(1,n),\ldots,(c,n)\} & \text{for level } n > 0.
\end{array}
$$

According to this partitioning the generator Q of the Markov process is given by:

$$
Q = \begin{pmatrix}
B_0 & B_1 & 0 & 0 & 0 & \cdots \\
B_{-1} & A_0(1) & A_1 & 0 & 0 & \cdots \\
0 & A_{-1}(2) & A_0(2) & A_1 & 0 & \cdots \\
0 & 0 & A_{-1}(3) & A_0(3) & A_1 & \\
\vdots & \vdots & \ddots & \ddots & \ddots & \ddots
\end{pmatrix}. \tag{19}
$$

The details of the sub matrices can be found in Appendix D. Let $\boldsymbol{\pi}_n$ be the vector of steady state probabilities at level n:

$$
\begin{aligned}
\boldsymbol{\pi}_0 &= \big(\pi_{0,0}, \pi_{1,0}, \ldots, \pi_{c,0}, \ldots, \pi_{S,0}\big), \\
\boldsymbol{\pi}_n &= \big(\pi_{0,n}, \pi_{1,n}, \ldots, \pi_{c,n}\big) \qquad n \in \mathbb{N}.
\end{aligned}
$$

Now Enders et al. (2014) introduce $\widetilde{\boldsymbol{\pi}}_n$ and the $(c+1) \times (c+1)$ matrix A:

$$
A = \begin{pmatrix}
0 & \cdots & 0 & 1 \\
\vdots & & \vdots & \vdots \\
0 & \cdots & 0 & 1
\end{pmatrix}. \tag{20}
$$

The $\pi_{m,n}$ can be determined with the following system of equations (See Appendix E for details of the derivation):

$$\begin{aligned} \tilde{\boldsymbol{\pi}}_0 B_0 + \tilde{\boldsymbol{\pi}}_1 B_{-1} &= 0 && \text{for } n = 0, \\ \tilde{\boldsymbol{\pi}}_0 B_1 + \tilde{\boldsymbol{\pi}}_1 A_0(1) + \lambda_2 \tilde{\boldsymbol{\pi}}_1 A &= 0 && \text{for } n = 1, \\ \tilde{\pi}_{S,0} &= 1, \end{aligned} \tag{21}$$

$$\tilde{\boldsymbol{\pi}}_n = -\tilde{\boldsymbol{\pi}}_{n-1} A_1 \left(A_0(n) + A\lambda_2\right)^{-1} \quad \text{for } n \geq 2, \tag{22}$$

$$\boldsymbol{\pi}_n = \frac{\tilde{\boldsymbol{\pi}}_n}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}. \tag{23}$$

Note that the steady state probabilities are normalized by fixing $\tilde{\pi}_{S,0} = 1$, instead of $\sum_{n=0}^{\infty} \boldsymbol{\pi}_n \boldsymbol{e} = 1$. Therefore (23) is necessary to normalize the steady state probabilities such that they sum up to 1. In other words, (23) can be used to change the $\tilde{\boldsymbol{\pi}}_n$'s back into $\boldsymbol{\pi}_n$'s.

6.2.6 Solution procedure

The performance measures in (15)-(18) can be reformulated with the use of (23):

$$\beta_1(S,c) = \frac{\sum_{m=1}^{S} \tilde{\pi}_{m,0} + \sum_{n=1}^{\infty} \sum_{m=1}^{c} \tilde{\pi}_{m,n}}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}, \tag{24}$$

$$\beta_2(S,c) = \frac{\sum_{m=c+1}^{S} \tilde{\pi}_{m,0}}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}, \tag{25}$$

$$I(S,c) = \frac{\sum_{m=1}^{S} m\tilde{\pi}_{m,0} + \sum_{n=1}^{\infty} \sum_{m=1}^{c} m\tilde{\pi}_{m,n}}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}, \tag{26}$$

$$B(S,c) = \frac{\sum_{n=1}^{\infty} n\tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}. \tag{27}$$

For the infinite sums a lower and an upper bound are used by Enders et al. (2014). These are based on the following function $U(\ell)$ (See Appendix F):

$$U(\ell) = \left(\tilde{\pi}_{0,\ell}, \tilde{\pi}_{1,\ell+1}, \ldots, \tilde{\pi}_{c,\ell+c}\right) \boldsymbol{e} (S+\ell)! \left(\frac{\mu}{\lambda}\right)^{S+\ell} \left[\frac{\lambda}{\mu} \phi(S+\ell-1) - (S-c)\phi(S+\ell)\right], \tag{28}$$

where

$$\phi(\ell) = e^{\frac{\lambda}{\mu}} - \sum_{k=0}^{\ell-1} \left(\frac{\lambda}{\mu}\right)^k \frac{1}{k!}. \tag{29}$$

This leads to the following bounding of the performance measures:

$$\frac{\sum_{m=1}^{S} \tilde{\pi}_{m,0} + \sum_{n=1}^{c+\ell} \sum_{m=1}^{c} \tilde{\pi}_{m,n}}{\sum_{n=0}^{c+\ell} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e} + U(\ell+1)} \leq \beta_1(S,c) \leq \frac{\sum_{m=1}^{S} \tilde{\pi}_{m,0} + \sum_{n=1}^{c+\ell} \sum_{m=1}^{c} \tilde{\pi}_{m,n} + U(\ell+1)}{\sum_{n=0}^{c+\ell} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}, \tag{30}$$

$$\frac{\sum_{m=c+1}^{S} \tilde{\pi}_{m,0}}{\sum_{n=0}^{c+\ell} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e} + U(\ell+1)} \leq \beta_2(S,c) \leq \frac{\sum_{m=c+1}^{S} \tilde{\pi}_{m,0}}{\sum_{n=0}^{c+\ell} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}, \tag{31}$$

$$\frac{\sum_{m=1}^{S} m\tilde{\pi}_{m,0}+\sum_{n=1}^{c+\ell}\sum_{m=1}^{c} m\tilde{\pi}_{m,n}}{\sum_{n=0}^{c+\ell}\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}+U(\ell+1)} \leq I(S,c) \leq \frac{\sum_{m=1}^{S} m\tilde{\pi}_{m,0}+\sum_{n=1}^{c+\ell}\sum_{m=1}^{c} m\tilde{\pi}_{m,n}+cU(\ell+1)}{\sum_{n=0}^{c+\ell}\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}}, \tag{32}$$

$$\frac{\sum_{n=1}^{c+\ell} n\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}}{\sum_{n=0}^{c+\ell}\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}+U(\ell+1)} \leq B(S,c) \leq \frac{\sum_{n=1}^{c+\ell} n\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}+U(\ell+1)}{\sum_{n=0}^{c+\ell}\tilde{\boldsymbol{\pi}}_n\boldsymbol{e}}, \tag{33}$$

where $\ell \geq 1$. To compute the performance measures started is with $\ell = 1$ and ℓ is increased, one unit at a time, until the distance between the upper and the lower bound is smaller than or equal to 10^{-6}.

To solve the optimization problem efficiently Enders et al. (2014) formulate a lower bound for the cost function, which is adapted here to the adapted cost function in (13):

$$C(S,c) \geq C_{LB}(S,c) \coloneqq c_t(\lambda_1\beta_1(S,c)+\lambda_2)+hS. \tag{34}$$

Furthermore consider the minimum cost for a fixed S, $\hat{C}(S)$, which can be bounded as follows:

$$\hat{C}(S) \geq \hat{C}_{LB}(S) \coloneqq c_t\lambda + h\left(S-\frac{\lambda}{\mu}\right). \tag{35}$$

Note that $c_t \leq c_t^{em}$ is chosen as a lower bound for the transportation cost for the lost sales (with demand rate $\lambda_1\beta_1(S,c)$).

Let $\hat{C}^*(S)$ denote the optimal costs up to a certain value of S and let $\tilde{C}^*(c)$ denote the optimal cost for a given S up to a certain value of c. Now the following optimization algorithm is used by Enders et al. (2014):

Algorithm 6.2: Find an OCL policy (S,c), Enders et al. (2014)

```
$S \leftarrow 0$
$\hat{C}^*(S) \leftarrow \infty$
while $\hat{C}^*(S) > \hat{C}_{LB}(S+1)$
do
    $c \leftarrow 0$
    $\tilde{C}^*(c) \leftarrow \infty$
    while $\tilde{C}^*(c) > C_{LB}(S,c+1)$
    do
        $C(S,c) \leftarrow EvaluatePolicy(S,c)$
        if $C(S,c) < \tilde{C}^*(c)$
            then $\tilde{C}^*(c) \leftarrow C(S,c)$
        $c \leftarrow c+1$
    $S \leftarrow S+1$
```

The bounding functions are both increasing in their variables, which is used to find the optimal policy. If the lower bound of the costs of a policy with $c = c+1$ is higher than the costs already found for that S, this means that a further increase of c would have a lower bound of the costs that is even higher. The same logic applies for an increase of S. Therefore the algorithm by Enders et al. (2014) always finds the optimal critical level policy when there are no fill rate constraints. The algorithm needs to be adapted to solve the problem stated in (14) with fill rate constraints.

To this end we use Theorem 1 . The first statement of Theorem 1 is proven by Enders et al. (2014). The second statement is assumed to be proven as well. Intuitively it is valid, because if c increases as S is fixed, the inventory that is available for class 2 customers decreases. Therefore the fill rate for these customers will also decrease.

Theorem 1 *The fill rates depend on* c *in the following manner:*

$$\begin{aligned} \beta_1(S,c) &\leq \beta_1(S,c+1) \quad i.e.\, \beta_1(S,c)\ is\ monotonically\ increasing\ in\ c, \\ \beta_2(S,c) &\geq \beta_2(S,c+1) \quad i.e.\, \beta_2(S,c)\ is\ monotonically\ decreasing\ in\ c. \end{aligned} \tag{36}$$

Similar to Enders et al. (2014), we start with $S \leftarrow 0$ and $c \leftarrow 0$. Now we increase S until $\beta_2(S,0) \geq \beta_2^{min}$. From this point on we find the optimal c for a certain S by using Theorem 1 . We start with $c \leftarrow 0$ for a certain S and keep increasing c, one unit at a time, as long as $\beta_2(S,c) \geq \beta_2^{min}$ and $\tilde{C}^*(c) > C_{LB}(S,c)$. The costs of a policy (S,c) is only evaluated if $\beta_1(S,c) \geq \beta_1^{min}$.

To find the optimal combination of S and c, we keep increasing S as long as the optimal cost up to a certain S are larger than $\hat{C}_{LB}(S+1)$ [note that $\hat{C}_{LB}(S+1)$ increases in S].

Algorithm 6.3: Optimize RSHQ (S,c)-policy

```
input ≔ $\beta_1^{min}; \beta_2^{min}; \lambda_1; \lambda_2; \mu; h; c_t$
$S \leftarrow 0$
$\hat{C}^*(S) \leftarrow \infty$
while $\hat{C}^*(S) > \hat{C}_{LB}(S+1)$
do
    $c \leftarrow 0$
    $\tilde{C}^*(c) \leftarrow \infty$
    $\beta_2(S,c) \leftarrow Evaluate\beta_2(S,c)$
    while $\beta_2(S,c) \geq \beta_2^{min}$ and $\tilde{C}^*(c) > C_{LB}(S,c)$
    do
        $\beta_1(S,c) \leftarrow Evaluate\beta_1(S,c)$
        if $\beta_1(S,c) \geq \beta_1^{min}$
            then $C(S,c) \leftarrow EvaluatePolicy(S,c)$
            if $C(S,c) < \tilde{C}^*(c)$
                then $\tilde{C}^*(c) \leftarrow C(S,c)$
        $c \leftarrow c+1$
        $\beta_2(S,c) \leftarrow Evaluate\beta_2(S,c)$
    if $\tilde{C}^*(c) < \hat{C}^*(S)$
        then $\hat{C}^*(S) \leftarrow \tilde{C}^*(c)$
    $S \leftarrow S+1$
output ≔ $\beta_1(S,c); \beta_2(S,c); \hat{C}^*(S)$
```

Note that this algorithm will be run twice for every item: for the two possible transportation modes. μ and c_t are different in these cases and the rest of the parameters are the same.

6.3 Service Level Control Unit

In 5.3 the choice was made to use an ABC-classification for the optimization problem. This implies that the service level targets for every location are determined per class and these service level targets are used for the items. To find the optimal service level targets, a manual search over possible targets is chosen as the solution method. This manual search is presented in 8.4.1.

6.4 Iteration between Control Unit 1 and 2

In 5.3.3.4 it was described that the Control Units 1 and 2 depend on each other in terms of expected waiting time and a demand process. In order to deal with this complexity, the following iteration is designed:

1. Fix the expected waiting time (due to non-availability at the CSC) for the RSHQ's to be equal to the lead time of the part at the CSC.
2. Execute model of Enders et al. (2014) once for every RSHQ to determine parameters and output of RSHQ's.
3. Execute model of Deshpande et al. (2003) to determine parameters and 'actual' expected waiting time at the CSC.
4. Fix the expected waiting time for the RSHQ's to be equal to the calculated expected waiting time at the CSC.
5. Iterate over step 2, 3 and 4 until the solution does not change anymore.

The starting point of this iteration (step 1) can be seen as an upper bound of the expected waiting time at the RSHQ, so an upper bound to the total costs at the RSHQ will be calculated in step 2. In step 3, the demand process, which is output of step 2, is used as input. The output waiting time of step 3 serves as input for the next iteration. With the test data set that is used for this research this iteration appeared to terminate very rapidly in every case.

7 Practical complexities

The final phase of the design methodology of Bertrand (2013) is the Integration Phase. In this phase, the models of the detailed design are integrated in a tool. Two major complexities have arisen during the design of the inventory control tool for Océ. These are the computational effort of the tool and finding a solution to the difference in the demand distribution, which is not a Poisson process in practice. In this chapter these complexities are described and the solution to these complexities is presented and analyzed.

7.1 Computational effort

The models that are used use quite fast optimization algorithms. Therefore the computation times of the models are not too high in many cases. It appeared, however, that the model of Enders et al. (2014), which is used for the RSHQ's, ran into an overflow error when the expected yearly demand was quite high. This means that the model does not work for fast movers if it is implemented exactly as it is described in the article. The reason that these problems occurred is that the mathematical model makes use of Markov-chain computations with a solution space that increases as the critical level increases. For fast movers, the critical levels appeared to get so high that the solution space got too large and the overflow error occurred. As can be seen from the results further on in 8.3.2, the fast movers cause most of the total costs in the system, so a solution that cannot be used for fast movers is not a useful solution.

7.2 Demand distribution

In general, the demand process for spare parts in a service supply chain follows a Poisson distribution. The Poisson process assumes that parts fail individually and independently of each other. In many cases this assumption is valid and for that reason most of the mathematical models about spare parts that are described in scientific literature are based on the assumption of a Poisson demand process. This assumption enables lots of analytical and optimization techniques, such that it is possible to find a solution in a reasonable amount of time.

Unfortunately at Océ the demand process at the RSHQ's does not follow a Poisson distribution (See Appendix C). There are at least two main reasons for this:

- Batching at downstream locations
- A dealer network to which parts are served

Since we only consider the upstream part of the supply chain in this research, the demand process is not generated directly by failure of parts. Downstream locations, such as car stocks and quick response stocks, face the demands that arise directly from customer orders. These locations order for replenishments at the next level upstream, for instance a national warehouse, which delivers them the parts. This location, on its turn, orders at the next level, which may be an RSHQ. In this chain of stock points there may be several different stock policies in use, which cause batched ordering at the next level. Due to this batched ordering, the demand variability for the next level increases, so at the most upstream part of the supply chain, the demand variability may have increased very much, which means that the demand process is not a Poisson process anymore.

7.3 Solution

First, a solution to both problems is sought by using a different model. Three scientific articles are found in which there is no assumption with regards to the demand distribution. Two of these (Cohen, Kleindorfer & Lee, 1988; Tempelmeier, 2006) have another invalid assumption though. They assume that there is no inventory in transit at the moment an order is placed. This assumption is not valid at all in this case, were generally several orders are open at the same time. The other model (Möllering & Thonemann, 2008) has no invalid assumptions, so this one seems to be very useful. It appears, though, that this model runs into computational problems that are even larger than those of the model of Enders et al. (2014). Especially when lead times or demand rates are high, the solution space becomes too large, so this model is not useful either.

The solution to the different demand distribution is found by adapting the demand rate and using a post-processing step to compensate for that. In Figure 7.1 the effect of this solution on the demand process is presented graphically. The actual demand rate is divided by the batch size, which in fact means that the assumption is made that every time a demand arises, this demand has this batch size. In Figure 7.1 this is showed as the number of bars with every batch size: the larger the batch size, the smaller the number of bars. The consequence of this method is that the variance of the demand process is increased, because there is batch ordering instead of single-unit ordering, which is an assumption of the Poisson distribution. The batch size is chosen such that the variance is as close as possible to the actual demand variance.

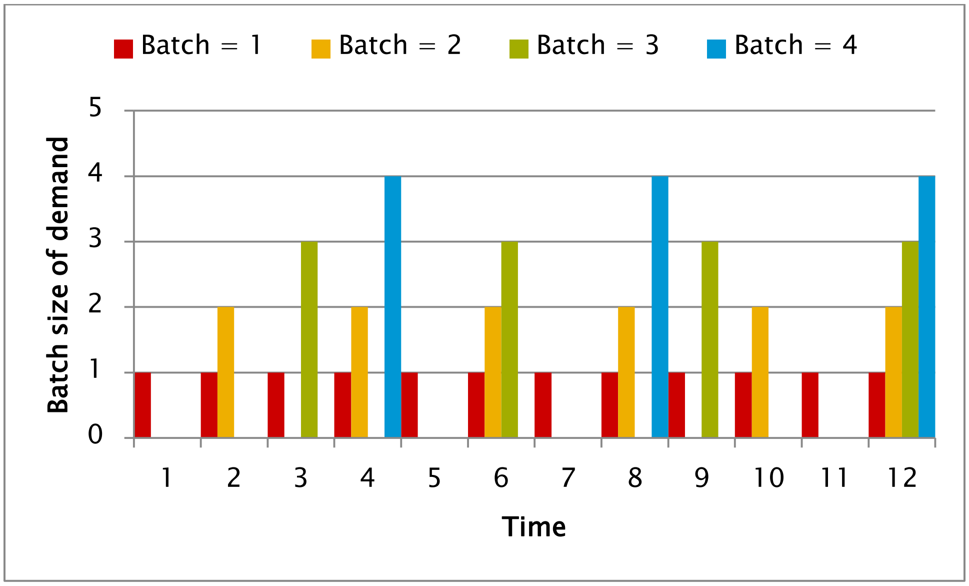

Figure 7.1: Effect of using batches on the demand process

By using this 'Batching' solution, the demand rate is decreased, which also increases the probability that a solution will be found and errors can be prevented. For some parts with a very high demand rate, the computational problems can still occur. Therefore the following error handling routine has been implemented for both models:

- Use the batch size with the closest variance to find a solution. If an error occurs:
    1. Increase the batch size of every order by 1 unit and thus decrease the demand rate.
    2. Use the new demand rate to find a solution. If an error occurs, iterate again.
- If no error occurs, multiply all output values by the batch size that was used to find the solution.

After finding a solution, the output values that are found should be multiplied by the batch size, such that the average yearly demand is kept equal to the input yearly demand. The effect of increasing the batch size is analyzed in detail in Appendix O. The conclusion is that this method makes sure that a feasible solution is found, the costs that are found form an upper bound of the optimal expected total costs and the fill rates that are found form a lower bound of the actual performance.

8 Results and Analysis

In this chapter the results of this research are presented and how these results have been established. The model is validated and this chapter also provides a sensitivity analysis on the choices that have been made because of practical implications.

8.1 Model verification

With model verification is meant that the model as it is described is correctly translated into the tool. To this end some different 'techniques' have been used.

First of all, the computer program is written in several smaller parts that are programmed in modules. In this way it is easier to debug after writing the code, because you can easily find out which parts of code contain errors by tracking the model part by part. Within each module the same logic has been applied by using functions and 'subs'. In this way every formula has been checked on its correctness.

A second technique has been to run the model with set of test input data and then argue if the outputs are reasonable. For instance the order-up-to level in the CSC should increase as the lead time increases. For all of the input parameters the values have been varied and the effect on the output has been examined and where needed, the code has been debugged.

Manual calculation is another technique of verification which has been applied. For a single part the model has been run with a very high fixed order-up-to level at the CSC such that the ample supply assumption at the RSHQ was valid. The order-up-to level and critical level at the RSHQ that were outputted were used as input for a manual calculation of the service levels and the costs for the part at the RSHQ. In a similar way the model of the CSC has been verified. (See Appendix I)

By applying all of these verification techniques, it is assumed that the tool is verified well.

8.2 Model validation

Validation of the model means making sure that the model is a good representation of the reality. Since the inventory control policies in the models are not yet used in practice it is not possible to compare the model output with real output. Other techniques should thus be used.

One of these used techniques is simulation. To represent reality a simulation model has been developed in which demand and replenishment events are handled as events that use simple logic to determine the inventory levels, backorders et cetera. This simulation model has been used with test data to determine whether the costs and service levels determined by the tool are consistent with the costs and service levels of the simulated reality. This has been done with Poisson demand for the implementations of the models of Deshpande et al. (2003) and Enders et al. (2014) separately to test the assumption of continuous review and the approximation that is used to estimate the lead time of the RSHQ's. For the combined model it is used to test the approximation of the lead time for the RSHQ's in the two-echelon system, which consists of the lead time approximation of the single-echelon model and the expected waiting time at the CSC. After that, the 'Batching' solution is also analyzed on its validity and impact on the solution.

From the simulation of the model for the CSC, based on Deshpande et al. (2003), it can be concluded that the continuous review assumption has no significant impact on the aggregate fill rates and costs. The simulation results are given in Table 8.1.

	Aggregate fill rate emergency	Aggregate fill rate regular	Total costs
Model	**97,52%**	**94,75%**	**€ 9,06**
Simulation Average	98,04%	94,55%	€ 8,76
Lower bound Conf int.	97,14%	92,95%	€ 8,36
Upper bound Conf int.	98,95%	96,15%	€ 9,16

Table 8.1: Simulation results for CSC-model with confidence intervals (α=0,05) for one test part (see Appendix J for details)

The results of the simulation of the model for the RSHQ's, based on Enders et al. (2014), can be found in Table 8.2. For this model it can also be concluded that the assumption of continuous review, together with the approximation method of the lead time, has no significant impact on the aggregate fill rate and total costs.

	Aggregate fill rate emergency	Aggregate fill rate regular	Total costs
Model	**99,40%**	**91,63%**	**€ 13,27**
Simulation Average	99,43%	90,93%	€ 13,13
Lower bound Conf int.	98,86%	88,96%	€ 12,50
Upper bound Conf int.	100,01%	92,90%	€ 13,76

Table 8.2: Simulation results for RSHQ-model with confidence intervals (α=0,05) for one test part (see Appendix J for details)

The approximation of the two-echelon system by combining the two single-echelon models is less accurate. In Table 8.3 the results of the simulation of the combined model can be found. At the RSHQ's the model underestimates the aggregate fill rates and the total costs are overestimated by the model. This means that the approximation of the waiting time for parts for the RSHQ's estimates a waiting time that is too high. Although this means that the model cannot be proven to represent the reality, the simulation demonstrates that the functional requirements are met, because the aggregate fill rates are even higher in practice than the model estimates and the costs are even lower.

	Beta1 CSC	Beta2 CSC	Beta1 RSHQ	Beta2 RSHQ	Total costs
Model	**97,19%**	**93,98%**	**99,43%**	**96,04%**	**€ 26,34**
Simulation Average	97,88%	93,36%	100,00%	99,76%	€ 25,68
Lower bound Conf int.	97,04%	91,10%	100,00%	99,25%	€ 25,16
Upper bound Conf int.	98,72%	95,63%	100,00%	100,26%	€ 26,20

Table 8.3: Simulation results of combined model with conf. intervals (α=0,05) for one test part (see Appendix J for details)

In Table 8.4 the results of the simulation of the combined model with the 'Batching' solution implemented can be found. The simulation shows that the model overestimates the total costs even more when the 'Batching' solution is implemented. The performance of the system is underestimated by the model. Compared with the model without the 'Batching' solution implemented, the results are positive, since without this solution the actual costs are higher and the actual performance is lower than the model finds. The underestimation of the fill rates of the system with the model with the solution ensures that a feasible solution is found and the functional requirements are met, which is good from a designer's point of view. It is less accurate though, which causes the results to be less easy to interpret.

	Beta1 CSC	Beta2 CSC	Beta1 RSHQ	Beta2 RSHQ	Total costs
Model	**99,90%**	**92,37%**	**99,89%**	**98,50%**	**€ 93,04**
Simulation Average	99,99%	99,63%	100,0%	100,0%	€ 82,34
Lower bound Conf int.	99,97%	99,29%	100,0%	100,0%	€ 79,18
Upper bound Conf int.	100,0%	99,93%	100,0%	100,0%	€ 85,27

Table 8.4: Simulation results of combined model with 'Batching' solution with conf. intervals (α=0,05) for one test part (see Appendix J for details)

Another technique of validation is to perform a sensitivity analysis. With a sensitivity analysis it can be determined which input variables have a significant impact on the output. The sensitivity analysis is described in 8.4.

8.3 Test results

After verification and validation the model can be tested, which is described in this section. Firstly, an introduction to the data set is given. Then the results of the test are described and compared with the inventory policy where the CSC keeps two separate stocks for the EMEA network and the RSHQ's. The results are generated with an item classification which is described and analyzed in detail in 8.4.1.

8.3.1 Data set

For the analysis of the designed model a data set is chosen to serve as input for the model. This data set consists of demand data and master data of every part of a certain machine: the Océ ColorWave 600. This machine is a wide-format printer that uses the Océ Crystalpoint® technology to produce high quality prints on a wide variety of media. It has a quite average part portfolio, with 141 parts of which 112 have faced some demand since 2013. The demand data consists of received orders at the RSHQ's in the USA, Singapore and China and the received orders at the CSC from all other sources than these RSHQ's. The reason that demand data of the other RSHQ's is not used directly is that this data is not stored properly in the information system. The difference between replenishment and emergency orders is only stored by Canon USA and the CSC, so the proportion of emergency demand of Canon USA is copied to the other RSHQ's. For the system to work more accurately it is recommended to make sure that all demand data is stored carefully and completely in the information system.

8.3.2 Overall results

The test data set has been classified based on the current XYZ-classification. A manual search has been performed to search for optimal fill rate targets for every demand stream. This manual search is elaborated with a sensitivity analysis in 8.4.1. In Table 8.5 and Table 8.6 the classification that was found with the manual search and the labels used in this test can be found for the CSC and the RSHQ respectively. The borders of the classification are set such that on the dimension price, 10% of the parts is placed in the high price class, 20% of the parts is placed in the medium price class and 70% of the parts is placed in the low price class. This results in an A,B or C. on the dimension demand rate, 10% of the parts is placed in the high demand class, 20% of the parts is placed in the medium demand class and 70% of the parts is placed in the low demand class. This results in a 1, 2 or 3, which together with the A,B or C defines the class of a part.

XYZ-Classification (CSC)		**High price (10%)**	**Medium price (20%)**	**Low price (70%)**
		A	**B**	**C**
Fast moving (10%)	**1**	**A1 (96%/81,55%)**	**B1 (98%/83,25%)**	**C1 (99,9%/84,86%)**
Medium moving (20%)	**2**	**A2 (94%/79,85%)**	**B2 (97%/82,4%)**	**C2 (98,5%/83,67%)**
Slow moving (70%)	**3**	**A3 (82,4%/70%)**	**B3 (92%/78,15%)**	**C3 (97%/82,4%)**

Table 8.5: XYZ-Classification for the CSC with item fill rates for emergency orders / regular replenishment orders

XYZ-Classification (RSHQ)		**High price (10%)**	**Medium price (20%)**	**Low price (70%)**
		A	**B**	**C**
Fast moving (10%)	**1**	**A1 (0%/94,02%)**	**B1 (0%/95,98%)**	**C1 (0%/97,84%)**
Medium moving (20%)	**2**	**A2 (0%/92,06%)**	**B2 (0%/95%)**	**C2 (0%/96,47%)**
Slow moving (70%)	**3**	**A3 (0%/80,7%)**	**B3 (0%/90,1%)**	**C3 (0%/95%)**

Table 8.6: XYZ-Classification for the RSHQ with item fill rates for emergency orders / regular replenishment orders

The main results of the model consist of an expected fill rate for every demand class and for every location, an expected aggregate fill rate for every location and the costs at every location. In detail an order-up-to level and a critical level are determined for every item and the fill rates per class per location can be found for every item. Also the choice for the transportation mode per item can be found in the detailed output and the costs per item (see Appendix H for detailed output data).

Location	CSC	RSHQ1	RSHQ2	RSHQ3	Total
Yearly costs	€ 21.403	€ 35.594	€ 6.199	€ 1.404	€ 64.600
Yearly costs (Separate stock policy CSC)	€ 18.525	€ 42.619	€ 6.979	€ 1.470	€ 69.593
Aggregate fill rate (Class 1)	97,23%	98,82%	97,42%	97,45%	
Aggregate fill rate (Class 2)	90,27%	97,06%	97,06%	96,07%	
Aggregate fill rate (Class 1, Emergency shipments included)	---	99,93%	99,84%	99,85%	
Aggregate fill rate (for both demand classes together)	90,66%	98,69%	98,60%	98,19%	

Table 8.7: Overall test results with comparison with separate stock policy at the CSC (see Appendix G for input data)

The test results show that the total relevant costs per year are €64.600 for all items of the Océ ColorWave 600 that have shown movement since 2013. The service levels as stated in the functional requirements are all met: for both the aggregate fill rate for the European network and the aggregate fill rate at the RSHQ's the target fill rate of 97% is met.

In Table 8.7 the test results for the designed model are compared to the case where the CSC separates their stock for the EMEA network from the stock for the RSHQ's, since this policy is opted to be used. In that case the fill rate constraints at the CSC were released for the demand from the RSHQ's. It can be seen that the total costs are €4.993 or 7% lower if the designed solution is used. This difference is made by keeping higher inventories at the CSC such that there is a pooling effect here and the inventory levels at the RSHQ's can be decreased.

With the designed solution the costs are still mostly made by the RSHQ's (67%) and about 33% of the total relevant costs are made by the CSC. One reason for this is that the transportation costs, including inventory carrying costs, are all counted for the RSHQ's. In total the transportation costs to RSHQ 1 (CUSA) are €16.977, which means that 48% of the total costs of this RSHQ are caused by transportation costs to the RSHQ. Holding costs at this RSHQ are €16.640, which is 47% of the total costs and the costs for emergency shipments from the CSC are €1.977, or 6% of the total costs. Another interesting observation is that 58% of the total costs are made by the two parts of the A1-category.

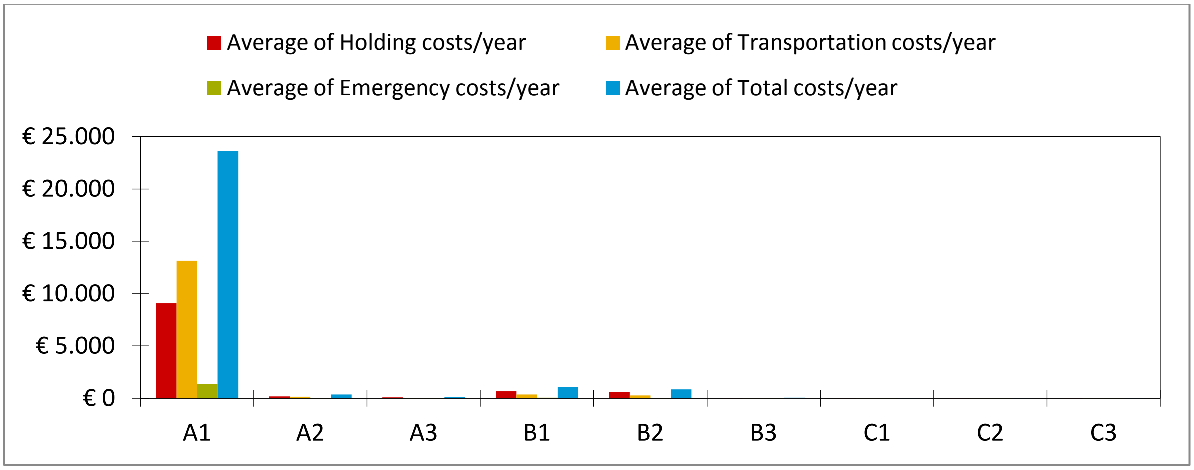

Figure 8.1: Average costs per part for every class at RSHQ 1 (CUSA)

For the RSHQ in the USA, the average costs per part are €375, but these differ a lot per part. In Table 8.8 these differences are visible (note that only 95 of the 112 parts have positive demand at the RSHQ). It can clearly be observed that the average costs for the more expensive parts are higher. Also the fast moving parts have higher costs, compared to slow movers. These cost differences are mainly caused by higher inventory and transportation costs. Note that these transportation costs include inventory holding costs for parts that are in transit, which explains the higher transportation costs for faster moving parts.

Class	Number of parts	Average of total costs per part per year
A1	1	€ 23.636
A2	3	€ 358
A3	4	€ 135
B1	2	€ 1.096
B2	7	€ 866
B3	13	€ 59
C1	6	€ 37
C2	13	€ 19
C3	46	€ 19
Grand Total	95	€ 375

Table 8.8: Average yearly costs per part per class at RSHQ 1 (CUSA) for 95 parts of the Océ ColorWave 600

In Figure 8.2 can be found how many items are transported via air shipments and how many over sea towards RSHQ 1. As can be seen from the figure, about 15% more parts are transported by sea transportation compared to air transportation. A detailed analysis shows that the heavier parts of more than 1 kg are almost always transported over sea, and that the lighter parts are transported more through the air (see Figure 8.3). It can also be seen that larger parts are shipped more by air and smaller parts are more likely to be shipped over sea. Another factor that is of influence is the interaction of price and demand: parts that have a higher price or a higher demand rate are more likely to be sent via air transportation, whereas cheaper parts or slow movers are more likely to be transported over sea. In Appendix K this analysis is described in further detail.

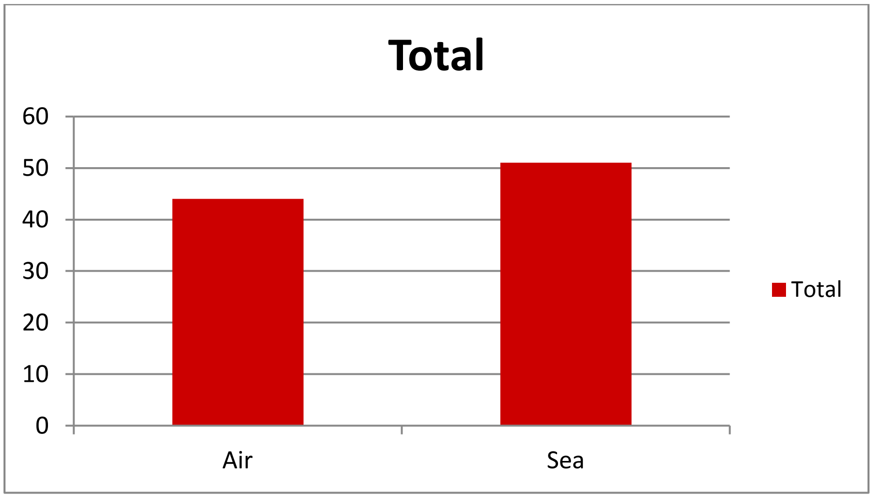

Figure 8.2: Number of items per transport mode for RSHQ 1 (CUSA)

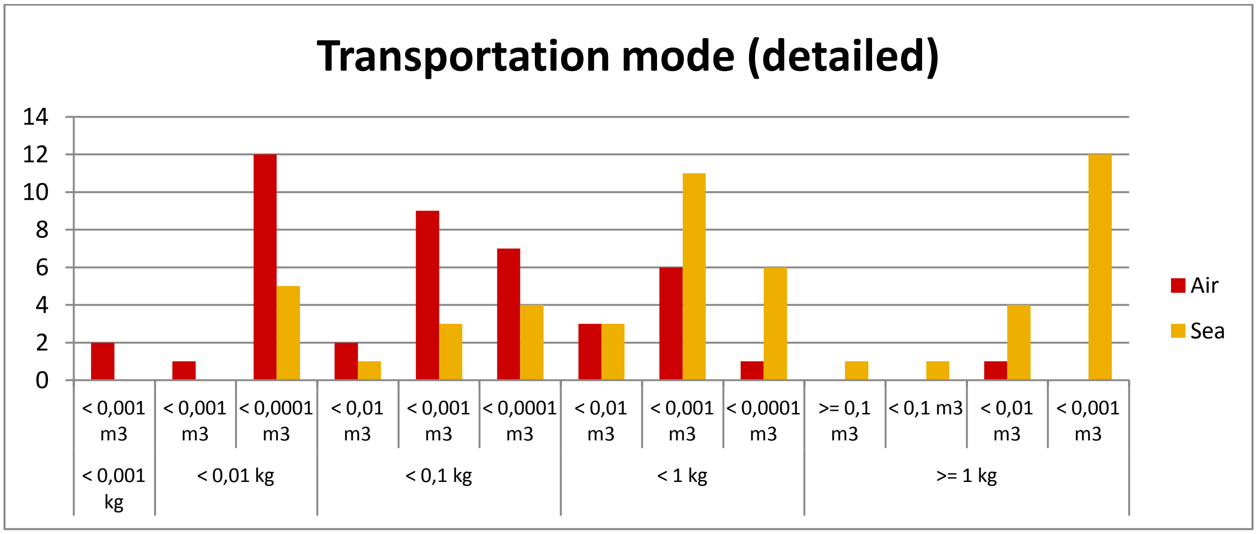

Figure 8.3: Number of items per transportation mode, sorted per weight and volume class (RSHQ 1, CUSA)

In Table 8.9 the order-up-to levels and critical levels at the RSHQ are summarized per class. It is clear that fast movers (A1, B1 & C1) have a higher S-level than slow movers (A3, B3 & C3). If the price of items is taken under consideration, some unexpected behavior is observed. For the fast moving parts, the expensive parts have a higher average S-level than the cheaper parts. An explanation can be found in the fact that the single part in class A1 that shows demand at this RSHQ has an extremely high demand rate, even compared to the other fast moving parts. For the slow moving parts, which form 70% of the total population of parts, the behavior is as expected. The critical levels are the highest for the fast moving cheap items and the lowest, always 0, for the slow moving expensive items. The reason for this lies in the tradeoff between additional holding costs, with the critical level, and additional emergency transportation costs. For cheap items, keeping a little bit more items on stock is cheap compared to the costs of emergency shipments. Especially with fast moving parts, this effect is leveraged even more. For expensive slow moving parts, the effect is the opposite.

Class	Average S-level	Average c-level
A1	126	0
A2	7,3	0,3
A3	2	0
B1	57	0,5
B2	54	0,3
B3	3,4	0,2
C1	93,5	1,7
C2	20	1,3
C3	13	0,7
Grand Total	22	0,7

Table 8.9: Average S- and c-levels per class at RSHQ 1 (CUSA)

Another expected observation that can be made from the results is that the S-levels at the CSC depend on the lead time of the part (See Figure 8.4). If this is taken into consideration it can be seen at the CSC as well that fast moving items have a higher S-level than slow moving items and that cheap items have a higher S-level than the expensive items.

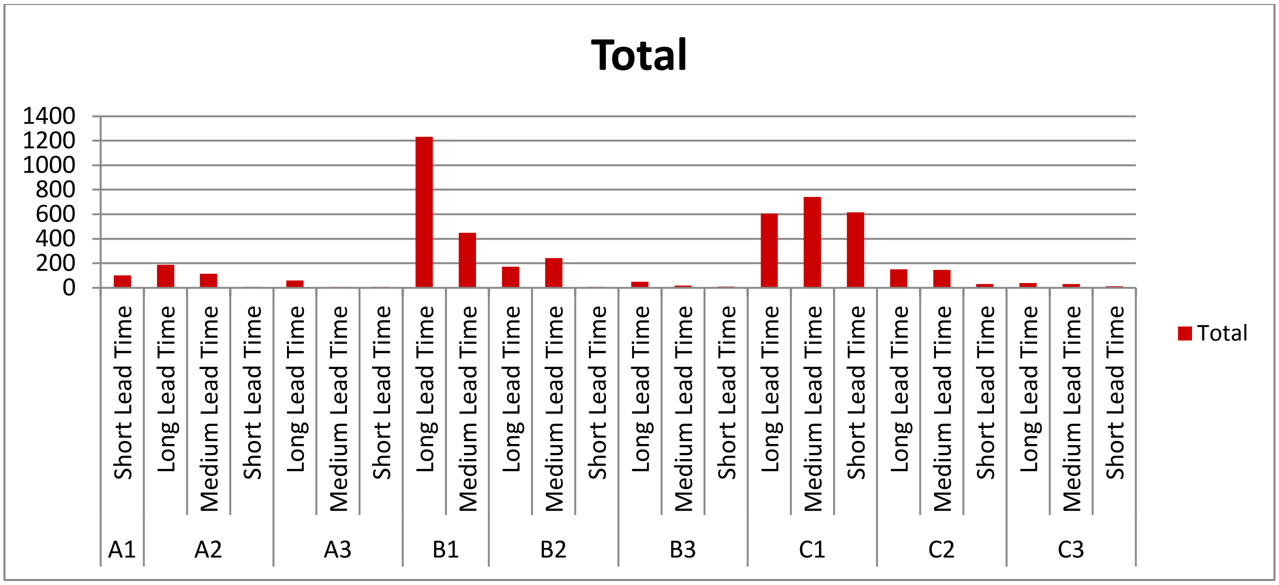

Figure 8.4: Average S-level per item at the CSC categorized with the ABC-classification augmented with a lead time dimension

8.4 Sensitivity analysis

In this paragraph the sensitivity analysis, which is part of the model validation, is described. The goal of this sensitivity analysis is to get insight in the influence of specific factors on the output of the model. The following questions are formulated to be answered via the sensitivity analysis:

- *What is the influence of a change in the classification of the parts on the expected total costs and the expected service levels?*
- *What is the influence of a change in the target fill rate for replenishment orders at the CSC on the expected total costs and the expected service levels?*
- *What is the added value of determining the transportation mode per item with regards to the total costs and the expected service levels?*
- *What is the effect on the expected total costs and the expected service levels if critical levels are not used?*
- *How sensitive are the expected total costs and the expected service levels to a change in the holding cost rate?*
- *How sensitive are the expected total costs and the expected service levels to a change in the transportation costs?*
- *What is the effect on the expected total costs and the expected service levels if the choice for a transport mode is predetermined?*

Firstly a closer look is taken to the classification of parts. Then the value of the choice for a transportation mode and the use of critical levels is examined. After that the model's sensitivity to the other input variables is treated.

8.4.1 Target fill rates and classification

This section gives an answer to the questions:

- *What is the influence of a change in the classification of the parts on the expected total costs and the expected service levels?*
- *What is the influence of a change in the target fill rate for replenishment orders at the CSC on the expected total costs and the expected service levels?*

The first question has arisen from the choice to do a manual search for the optimal service levels per class. As a starting point the currently used XYZ-method is taken. The second question arises, because the target fill rate for replenishment orders at the CSC has now been fixed at a minimum of 82,4%, but releasing this constraint may yield more.

Currently, Océ uses a method called XYZ to classify the spare parts. The XYZ-method classifies the parts on the basis of three dimensions: demand, price and frequency. The dimension 'frequency' is used for the choice whether to control the inventory of a part with a forecast or a simple reorder point. The safety stock, in fact, does not have to depend on this choice for the planning method. Therefore the classification that is used in this analysis has two dimensions: Demand (fast, medium or slow moving) and price (high, medium or low price). Currently, the XYZ-method specifies, for the CSC, which item fill rates should be set in order to satisfy the aggregate target fill rate of 97% (Table 8.10).

XYZ-Classification	High price (10%)	Medium price (20%)	Low price (70%)
Fast moving (10%)	97%	98%	99,5%
Medium moving (20%)	96%	97%	98%
Slow moving (70%)	90%	95%	96%

Table 8.10: Current XYZ-classification for inventory control

The functional requirements (see 5.1) specify that the aggregate target fill rate for emergency orders and regular orders should be 97% at each RSHQ and at the CSC for demand from the European network. The XYZ-classification is used at every location for the emergency demand streams and at the RSHQ's for the regular demand stream as well. For the regular orders at the CSC an aggregate target fill rate of 82,4% is specified, since this target has been determined by the manager of the department SCM Service Parts 1 to be a lower bound to keep the system stable. This target is approximated by proportionally adapting the target fill rates of the XYZ-classification, which is used as a 'basis scheme'. This classification determines a starting point for the sensitivity analysis on the classification (case 1). In this way an upper bound to the costs of € 71.536 is calculated.

As can be seen from the results for case 1 (Table 8.12), the fill rates for emergency orders at the RSHQ's are a lot higher than their targets of 97%. For this reason the fill rate constraint for emergency orders at the RSHQ's is released (case 2). The results of case 2 show no change at all compared to case 1. This means that the fill rate target for emergency orders does not have an impact on the results of case 1. The effect of releasing the fill rate constraint on the ultimately chosen test case is very small as well. The impact on the aggregate fill rate for emergency requests at the RSHQ's is less than 0,5% and the cost decrease is 7%. The most probable reason that the aggregate fill rate is nearly unaffected is that the high costs for not having a part available (i.e.: the emergency transportation costs) already ensure a very high fill rate for the emergency demand class. The cost decrease is caused by some slow moving items for which the fill rate constraint is more constraining than the costs for non-availability.

Another observation of the results of case 1 is that the aggregate fill rate targets at the RSHQ's are also exceeded largely. Therefore the fill rate targets of the regular orders at the RSHQ's are set lower to 95% (case 3). It can now be observed that the total costs of case 3 are about 7% lower compared to case 1. The fill rate targets are still met easily.

Improved Classification	**High price (10%)**	**Medium price (20%)**	**Low price (70%)**
Fast moving (10%)	**96%**	**98%**	**99,9%**
Medium moving (20%)	**94%**	**97%**	**98,5%**
Slow moving (70%)	**82,4%**	**92%**	**97%**

Table 8.11: Improved classification for inventory control

Finally the classification might be improved by changing the fill rate targets in the 'basis scheme'. Several options have been tried out, of which the best is presented here as case 4 (Table 8.11). It can be seen that the differences between the classes are leveraged more, which has the impact that costs decrease with another 2,6% to € 64.600, while the overall fill rate targets are only marginally affected. Note that 82,4% is set as the target for the expensive slow moving parts, again since this target is thought to be a 'minimum' to keep the CSC reliable enough. This classification is used as a reference in the rest of this sensitivity analysis and was used to generate the test results in section 8.3. If the constraint of 82,4% is decreased to 70%, the total costs can be decreased with another 1,6% to about € 63.575. An analysis of releasing this constraint can be found in Appendix L.

			Case 1	Case 2	Case 3	Case 4 (optimal)
Aggregate fill rates	CSC	Emergency	97,21%	97,21%	97,21%	97,23%
		Regular	91,01%	91,01%	91,01%	90,27%
		Total	91,35%	91,35%	91,35%	90,66%
	RSHQ (CUSA)	Emergency	99,11%	99,11%	98,85%	98,82%
		Regular	98,12%	98,12%	96,91%	97,06%
		Total	99,16%	99,16%	98,63%	98,69%
	RSHQ (CSPL)	Emergency	98,76%	98,76%	98,29%	97,42%
		Regular	98,60%	98,60%	97,78%	97,06%
		Total	99,34%	99,34%	98,97%	98,60%
	RSHQ (CCN)	Emergency	99,42%	99,42%	98,07%	97,45%
		Regular	98,20%	98,20%	96,38%	96,07%
		Total	99,20%	99,20%	98,36%	98,19%
Costs	Total		€ 71.536	€ 71.536	€ 66.295	€ 64.600

Table 8.12: Sensitivity analysis of the ABC-classification

Another possible improvement, which is not examined here, is the use of emergency shipments for both regular and emergency demands. This may be wise to use for expensive parts that are really slow moving, because keeping one part on stock at every RSHQ might be more costly than keeping no parts on stock at the RSHQ's and using an emergency shipment every time that a demand arises. It is not possible to set this in the designed tool though, since the focus of the tool is on the difference between regular replenishment orders and emergency orders.

With the item classification shown in Table 8.11 a further sensitivity analysis on the target aggregate fill rate of regular replenishment orders at the CSC has been performed. The results of this sensitivity analysis are presented in Figure 8.5. It can be seen that the effect of a change in target aggregate fill rate for regular orders at the CSC has quite a significant impact on the actual fill rate for regular orders at the CSC. The effects on the total costs vary a lot less. At the cost of a fill rate decrease of 18%, a cost decrease of only 1% can be made. On the other hand, improving the fill rate with 7,4% can be done with a total cost increase of 2,4%. It is noteworthy though, that the perceived fill rates for demand at the RSHQ's were not affected at all by decreasing the fill rate targets of the regular orders at the CSC.

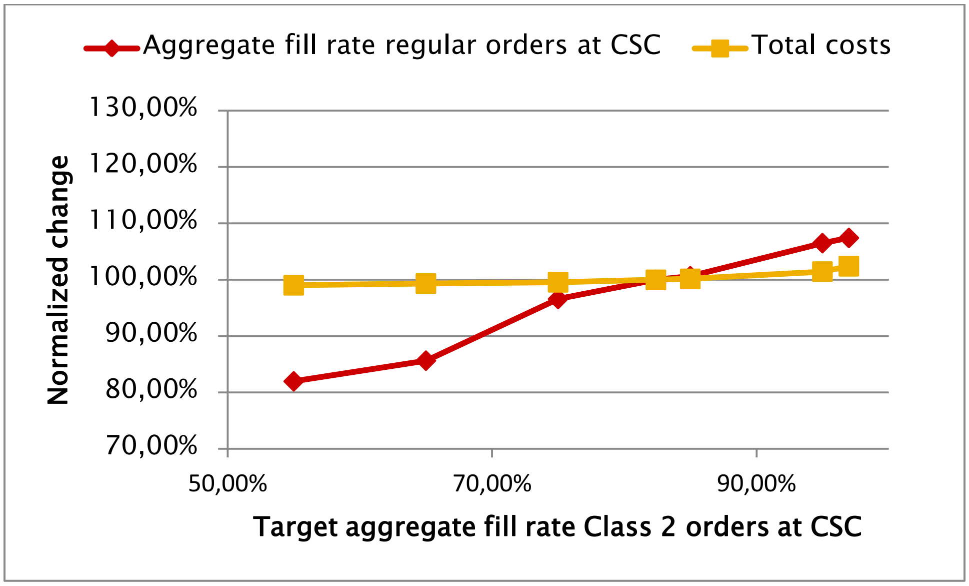

Figure 8.5: Sensitivity analysis of the target aggregate fill rate for regular replenishment orders at the CSC

In conclusion the following observations can be made from the sensitivity analysis of the fill rates and the ABC-classification. Firstly, the fill rate constraint of the emergency order class at the RSHQ's may be released. This has a small positive effect on the total costs. With regards to the aggregate service level there is not a significant effect. Secondly, the fill rate targets for the regular replenishment order class at the RSHQ's do effect the outcome. Costs decrease with 7% if the aggregate fill rate target is set to 95% instead of 97%. A deeper analysis on changing this fill rate target can be found in Appendix M. Furthermore, the 'basis scheme' of the classification can be improved. A case that yields a total costs decrease of 2,6% was found; this change in fill rate targets had no significant impact on the aggregate service level. Finally the target aggregate fill rate for regular orders at the CSC does not have a high impact on the costs. A decrease to 55% yields a cost decrease of 1%, which is not really significant and in order to stay reliable it is not desirable to decrease this service level even further. Therefore, the target of 82,4%, which actually yields an aggregate fill rate of 90%, should be kept.

8.4.2 Transportation mode

The model uses both sea transportation and air transportation, but currently the transportation modes to some RSHQ's are fixed. Every part is then sent over sea. To this end, this section takes a close look at the effect on the expected total costs and the expected service levels if the choice for a transport mode is predetermined.

Because only the transportation mode to one of the RSHQ's (CUSA) has been varied, the total costs of this RSHQ only are taken for the sensitivity analysis. From Figure 8.6 it can be observed that the choice for a transportation mode does have a significant impact on the total costs for the RSHQ. These are 55% higher if it is predetermined to use only sea transportation to the RSHQ. The effect of fixing air transportation is smaller, but still significant (11%). The reason that these differences are so high for sea transportation is mainly caused by the higher costs for the inventory that is in transit to the RSHQ's. Fixing all items to be sent by air causes high costs for parts that could be sent cheap over sea. The effect on the aggregate fill rate is very small (<0,1%). These figures show that the value of the model's functionality to determine the transportation mode is very high. Compared to the current operations, where sea transport is used as standard shipment mode, the costs can decrease with 35%.

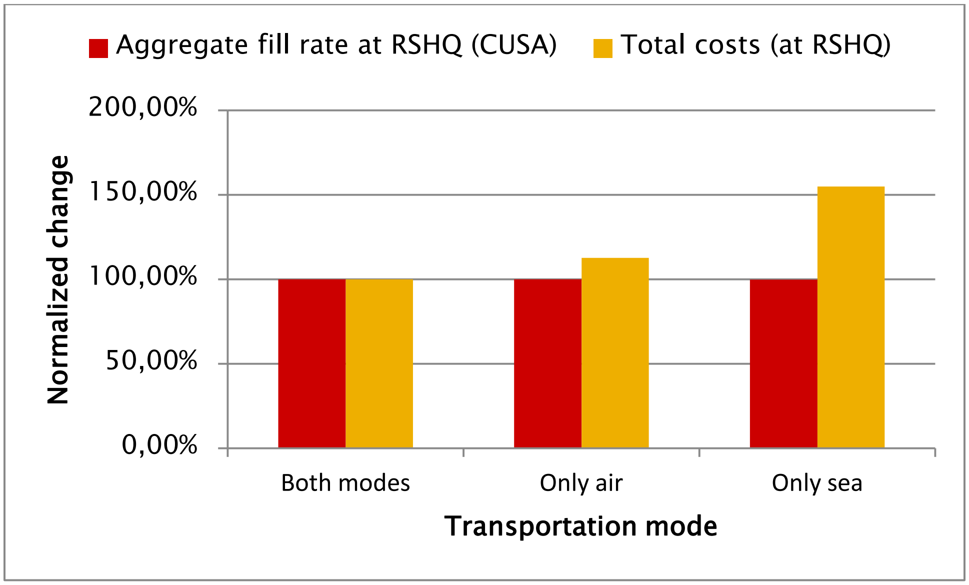

Figure 8.6: Sensitivity analysis of a predetermined transportation mode to an RSHQ (CUSA)

8.4.3 Critical levels

Currently Océ does not use critical levels, but reserving parts for emergency requests is done arbitrarily by the planner. In this section it is examined whether the difference in expected total costs and service levels is high when critical levels are used. In Table 8.13 the results of this analysis are shown. From this table it can be observed that there is a significant impact on the aggregate fill rate of the RSHQ. The reason for this is that without a critical level the expected fill rate for regular orders is equal to the expected fill rate for emergency orders for every part, which means that the expected fill rate for regular orders is higher than the target. Using a critical level affects the item fill rates in such a way that the expected fill rate for regular orders is closer to the target. The critical level at the RSHQ has only a small impact on the costs though. At the CSC the critical level has a higher value. A cost decrease of about 2,4% can be reached by using a critical level at the CSC and 2,5% if they are used at both locations.

Locations where critical level are used	Aggregate fill rates CSC			Aggregate fill rates RSHQ1			Total costs
	Emergency class	Regular class	Total	Emergency class	Regular class	Total	
No critical levels	97,4%	97,4%	97,4%	98,8%	98,9%	99,5%	€ 66.279
RSHQ	97,4%	97,4%	97,4%	98,9%	97,2%	98,7%	€ 66.163
CSC	97,2%	90,3%	90,7%	98,8%	98,9%	99,5%	€ 64.716
RSHQ and CSC	97,2%	90,3%	90,7%	98,8%	97,1%	98,7%	€ 64.600

Table 8.13: Sensitivity analysis of the effect of using critical levels on the aggregate fill rates and total costs

8.4.4 Holding cost rate

To understand how sensitive the expected total costs and the expected service levels are to a change in the holding cost rate, a sensitivity analysis has been performed where the holding cost rate has been varied at the CSC and at the RSHQ. The results are similar, so only the results for changing the holding cost rate at the RSHQ are shown here in Figure 8.7. From these results it can clearly be seen that an increase in the holding cost rate causes an increase in the total costs, has almost no effect on the aggregate rill rate at the RSHQ. The obvious reason for this is that costs for the entire inventory increase, when the holding cost rate increases. The effect on the solution (i.e.: the parameter settings per item) are small. In Appendix N a detailed description of this analysis is given. The conclusion is that if the holding cost rate increases, some items are transported by air instead of sea, these items then have a lower order-up-to level as well, but the same critical level. Another effect is that for some items the order-up-to levels and the critical levels harmonically decrease slightly. With harmonically is meant that both levels show the same decrease.

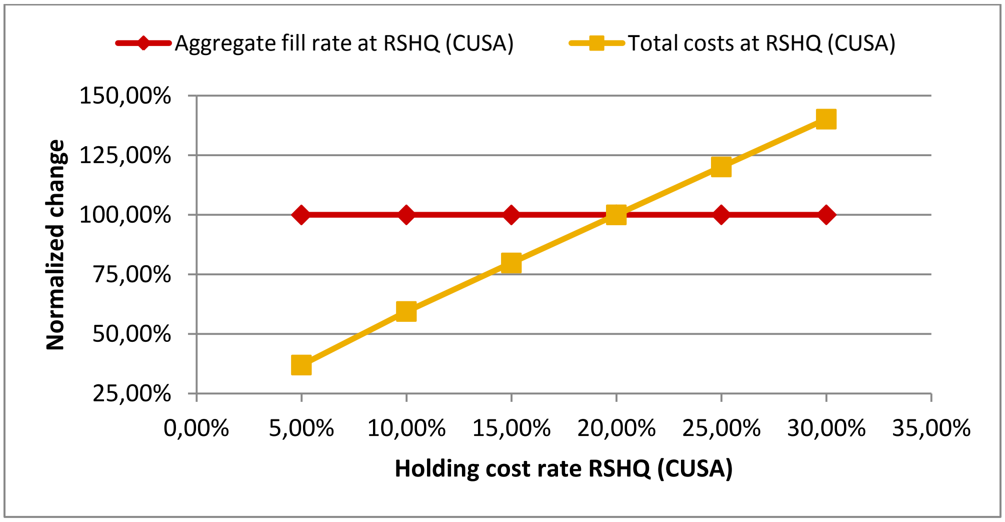

Figure 8.7: Sensitivity analysis of the holding cost rate at an RSHQ (CUSA)

A change in the holding cost rate at the CSC only affects the costs, similar to a change of the holding cost rate at the RSHQ, but it has no impact on the order-up-to levels. So in conclusion it can be mentioned that it is important to use an accurate holding cost rate, because the impact on the costs is high. The impact on the found solution and on the performance is very low though, so for operational purposes it is not a factor with a high impact.

8.4.5 Transportation costs

This section gives an answer to the question how sensitive the expected total costs and the expected service levels are to a change in the transportation costs. For this purpose, the transportation costs of both transport modes have been varied as well as the transportation costs for an emergency shipment.

A change in the costs for sea transport only has a very small impact on the costs. A 63,5% decrease of transportation costs per m3 only yields about €176, which is a decrease of 0,27%. The aggregate fill rate at the RSHQ is nearly not affected.

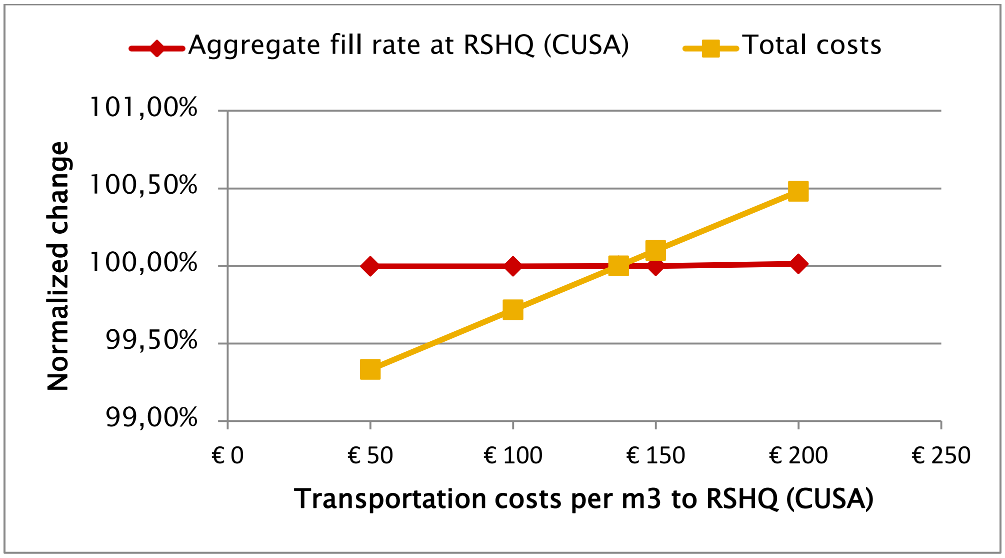

Figure 8.8: Sensitivity analysis of the sea transportation costs at an RSHQ (CUSA)

For air transportation, the impact on the costs is larger, whereas the effect on the aggregate fill rate is very small again. A decrease of 67% of the air transportation costs per kg yields about €3.381, which is 5,2%.

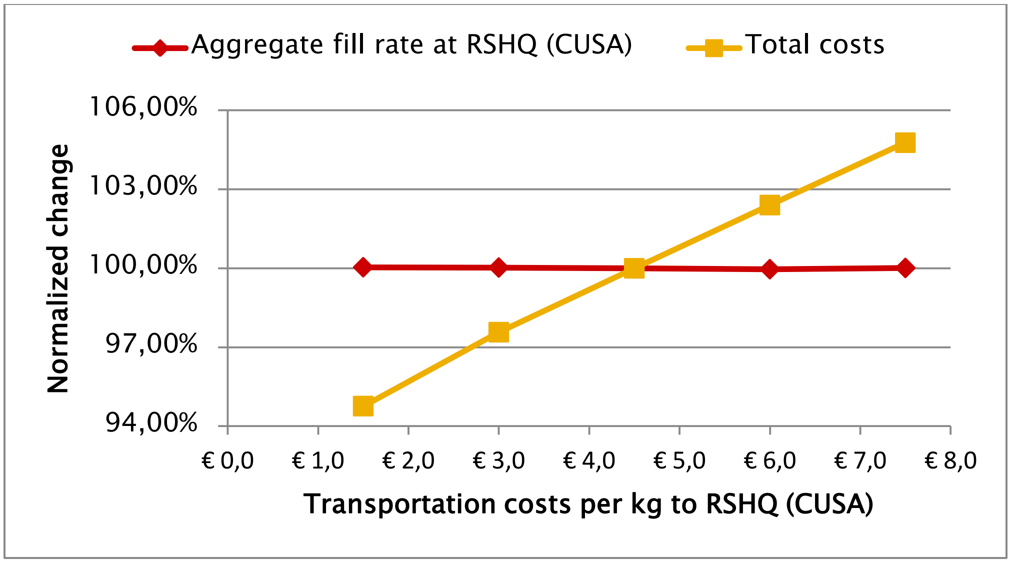

Figure 8.9: Sensitivity analysis of the air transportation costs at an RSHQ (CUSA)

A change in the transportation costs for emergency shipments also has some impact on the total costs. The aggregate fill rate is again nearly unaffected.

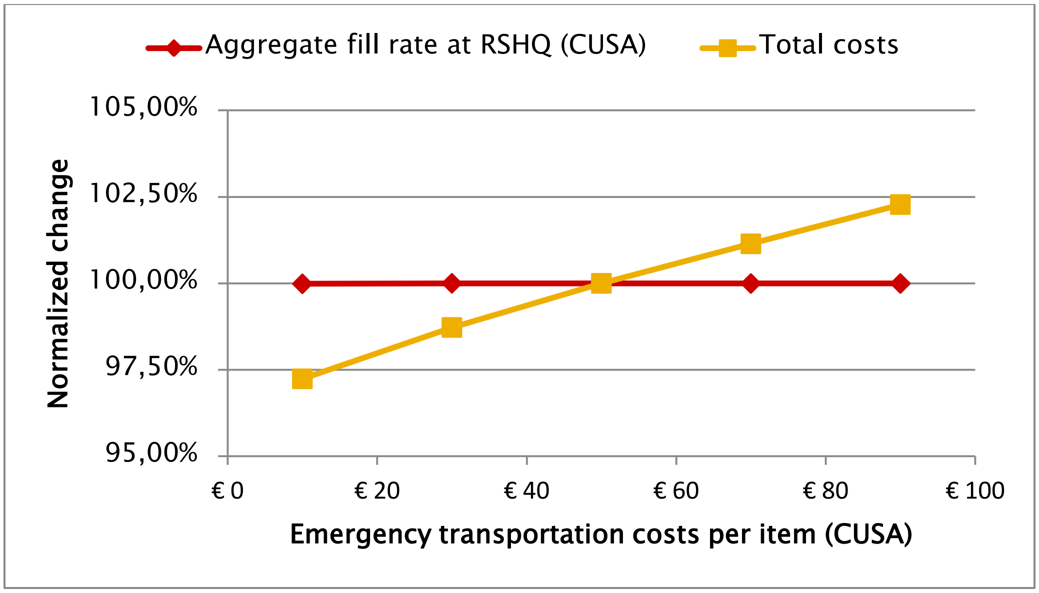

Figure 8.10: Sensitivity analysis of the emergency transportation costs at an RSHQ (CUSA)

It can be concluded that the transportation costs have a small impact on the total costs, but they do not really affect the performance with regards to the aggregate fill rate. A close look at the parameter settings that are outputted by the model reveals that the impact is also small here. If the transportation costs for emergency shipments increase, the order-up-to levels and critical levels increase at the same time for some items.

8.4.6 Conclusion

The model that is designed for the control of the spare parts inventories at the RSHQ's and the CSC in Venlo has been verified and validated. From the validation it is known that the model calculates an upper bound of the expected costs and a lower bound of the expected aggregate fill rates. A data set consisting of demand data and master data of all parts of one machine (ColorWave 600) has been used to generate the test results.

These test results show that on average a yearly cost of about € 64.600 should be made in order to satisfy the fill rate constraints. 58% of these costs are made for the A1-category, in which the expensive fast movers can be found. The cost difference between the designed policy and the policy with a separate stock at the CSC for the EMEA network is 7%. Unfortunately it is not possible to show a comparison with the current performance and cost figures, since they are not yet transparent throughout the service supply chain after the integration of Océ and Canon. Nevertheless it can be expected that the integrated approach that is used in this research and in this tool will perform better than the current way of working, where there is no transparency and only little cooperation between the different echelons. The tool is overestimating the costs, so the actual costs if the solution is implemented will be even lower.

From the sensitivity analysis the following conclusions can be drawn:

- The item classification has a significant impact on the total costs and on the service levels. The expected costs can be decreased with at least 1,6% if the item classification is improved, without affecting the aggregate service levels.
- The target aggregate fill rate for regular replenishment orders at the CSC has a small impact on the costs and no impact on the aggregate service levels. Only a cost decrease of 1% can be made if the target aggregate fill rate is decreased to 55%. Therefore a higher target aggregate fill rate of at least 80% should be used.
- If the choice for a certain transportation mode is predetermined at an RSHQ, the total costs at the RSHQ increase. This increase is 11% if air shipments are fixed; fixing sea transportation has an impact of 55% on the total costs for the RSHQ.
- Using critical levels has especially value at the CSC. A total cost decrease of 2,5%, of which 2,4% is caused by the CSC, can be reached if critical levels are used at both locations, compared to not using them.
- A change in the holding cost rate has a large impact on the total costs, but only a small impact on the solution and the expected fill rates. Specifying an accurate holding cost rate is important in order to give a reasonable cost estimate, but it is less important with regards to the solution.
- A change in the transportation costs has a moderate impact on the total costs, especially air transportation costs and costs for using an emergency shipment. The solution and the expected fill rates are nearly unaffected, though. So the fact that these costs fluctuate a lot has not a large impact on the solution, only on the cost estimate.

9 Implementation issues

Implementing a theoretical model in practice always brings along some implementation issues. The most important ones are described in this chapter. These are: fitting the output of the tool to the information systems in use; implementing the ABC classification in practice; making the model understandable for Océ's employees who are expected to work with it; making sure that the input values for the model are correct and keeping the model up to date.

9.1 Fitting the output to the information systems

The CSC in Venlo and the RSHQ's use different information systems. It has been agreed with Canon that 'their' GAIA system will be used as a sort of interface between the SAP system of Océ and the information systems that are used by the RSHQ's. The SAP system of Océ and GAIA both use a safety stock level for every part to control the inventory levels. The output of the models used in the tool is a set of order-up-to levels and critical levels. This means that the order-up-to level needs to be 'translated' in a safety stock level such that it can be implemented in practice. To do this, the following formula can be used in a post-processing step:

$$ss = S - \lambda * LT \tag{37}$$

The reasoning behind this formula is that the order-up-to level S is formed by the expected demand during the lead time of the part and a safety stock to prevent for unavailability. At the CSC, the lead time to the CSC of the part is taken as parameter for this post processing step. At the RSHQ's the lead time is formed by the lead time from the CSC, an expected waiting time for the part at the CSC and an expected waiting time until an order is placed, caused by the periodic review: $LT = L + \frac{1}{2}R + W$. Here, L denotes the lead time from the CSC to the RSHQ, R denotes the review period and W denotes the expected waiting time for the part at the CSC.

The critical level is another implementation issue, since GAIA and SAP do not yet have such a parameter included. In order to make use of the critical level, it is important that the information systems are adapted in such a way that the critical level can be included as a parameter.

9.2 Implementing the ABC classification in practice

The ABC-classification used in this design is based on two dimensions: 'part price' and 'average demand'. In 5.3.1 it was described to use 'frequency' as a dimension as well. Currently this is done in order to determine whether a part is controlled with the use of a forecast or a simple reorder point. This method has proven to be beneficial, so this should be kept in use. With both inventory control methods the safety stock level is used as the parameter to determine the reorder moment. Therefore the safety stock level determined by the model with the use of (37) can be used for both frequently and infrequently demanded items.

The implementation of the ABC classification is a large issue for the GAIA system of Canon. At the moment it is possible to classify parts, but only on the dimensions 'demand rate' and 'frequency'. From the sensitivity analysis we know that the price of a part has a significant impact on the inventory control of the part (see 8.4). It is therefore important that in some way the price of the part will be included in the classification of the parts for the sake of cost and service level optimization. The best way to do this would be to change GAIA in such a way that the part price can be included in the item classification. Another option would be to set the safety stock levels and critical levels for every part without using the classification.

Océ itself is already using a classification based on the three dimensions used in this research, so the implementation is no big issue at the CSC. It is only necessary to change the target fill rates per item for every class to the new values (See 8.4.1).

9.3 Making the model understandable

The first parts of making the model understandable to the employees are formed by this thesis and by the explanatory presentation given to the employees of Océ, where the model is explained and questions can be answered. Secondly, the model is given a user interface that is easy to work with and a user manual is written to support the use of the model and give insight in the meaning of the output.

9.4 Making sure that the input is correct

The model uses a lot of different input parameters, to some of which the output is quite sensitive. At the moment the demand data that is registered in the information system S-CUBE is not complete and not accurate for all of the RSHQ's. The RSHQ's in Korea and Australia are not yet included in S-CUBE, but they will be included in the future. But more important is the accuracy of the data. It appears that only the RSHQ in the USA registers for most of their incoming orders whether it is a regular replenishment order or an emergency request. The other RSHQ's that are in S-CUBE do not register this, which is really affecting the output of the model. An analysis of this is given in Appendix P. If the RSHQ specifies all demand to be an emergency request (as currently done by several RSHQ's), the costs at the total costs increase with at least 4%. All of these extra costs are made at the RSHQ. In order for these RSHQ's to receive good and accurate inventory control proposals from the CSC it is very important that they make sure to register consequently whether a received order is a regular replenishment order or an emergency request.

Other input parameters could also not be accurately used for testing the model, such as the weight and volume of parts, which are not always stored in the information system, and the costs for transportation, which are now based on estimates of an expert employee instead of actual figures. The output of the model is not really sensitive to the costs for transportation, but it is still important to use the right values in order to give value to the model. With regards to the dimensions of the parts, it is important to keep these accurately, since they have a significant impact on the output of the model. It is recommended to use one standard measure for each dimension, because it is not clear at all at the moment, with measures varying from cm^3 to US gallons.

9.5 Keeping the model up-to-date

In order that the model can be used in the future it is important to keep it up-to-date. This means that the model needs to be ran every month to determine the safety stock levels, such that Océ and the RSHQ's can react to changes in the demand pattern of parts.

Besides the monthly runs it is recommended to take a close look at the item classification on a regular basis. From the sensitivity analysis it is known that the item classification has a significant impact on the output of the model, so if something has changed in the portfolio of parts, the item classification may be improved.

It may also occur that the tool needs to be adapted or re-implemented, due to for instance the use of a new version of Microsoft Excel. To this end, all of the coding is accommodated with explanation about what every line is meant for. In chapter 0 the models that are used are described in detail, such that the implementation can be adapted or done over in the case that this is necessary.

10 Conclusions and recommendations

In this chapter conclusions are drawn from the research described in this thesis in section 10.1. In section 10.2 recommendations are given to Océ about the inventory control of the spare parts. Section 10.3 describes some interesting opportunities for future research that have arisen from this research.

10.1 Conclusions

The research described in this thesis was based on the following research objective: "*Develop a multi-item, multi-echelon inventory control policy for the CSC and the RHSQ's in order to minimize total costs against given service level constraints and implement this in a tool".* The design method as described by Bertrand (2013) has been used to work structurally towards this objective.

Based on the characteristics of the distribution network of Océ and the literature, the following inventory control policy has been determined in chapter 5 in order to minimize the total relevant costs.

An order-up-to level should be used at the RSHQ's, which means that at every review period an order is placed that increases the inventory position to the order-up-to level. In order to find the minimal costs, the transportation mode used for transport to the RSHQ's should be determined by the model for every part. In order to differentiate between the two customer classes a critical level should be used, such that if the inventory decreases below this level, only emergency requests are fulfilled. In case of non-availability of a part an emergency shipment from the CSC should be requested for emergency demand. Demand for regular replenishments should be backordered.

At the CSC an order-up-to level should be used as well, similar to the RSHQ's, together with a critical level to differentiate between regular replenishment orders from the RSHQ's and demands from the EMEA network and emergency requests originating from non-availability at the RSHQ's. The inventory of the CSC should be used both for demands of the EMEA network and for demands of the RSHQ's in order to benefit from inventory pooling effects.

This policy has been compared with the policy where the CSC keeps two separate stocks for the EMEA network and the RSHQ's. The total costs for the designed control policy are 7% lower compared to the separate stock policy at the CSC. Using critical levels is the most beneficial if it is used at the CSC. The costs decrease with 2,5% if critical levels are part of the inventory control policy. At the RSHQ's the benefit of using critical levels is small. When the choice for one of the possible transportation modes is made separately per part, the total yearly costs are 35% lower compared to using sea transportation as a standard for every part, which is used currently.

A tool has been developed based on chapters 0 and 0, which determines the optimal order-up-to levels and critical levels at each location for every part. It also determines whether to use sea transportation or air transportation to the RSHQ for every part. The tool is based on the models of Deshpande et al. (2013) for the CSC and Enders et al. (2014) for the RSHQ's. Since these two models use an item approach, it is important to use an optimal item classification that specifies the target fill rates for every demand stream per item. The classification described in 8.4.1 is a manually found optimum. This may be improved even further though.

On aggregate, the target fill rate for priority class demand at the CSC, which is formed by every demand from the European network and emergency requests from the RSHQ's, should be set at 97% in order to meet the required service requirements of the EMEA network. The target aggregate fill rate at the CSC for regular orders from the RSHQ's should be set at least at 80% in order to be reliable enough for the RSHQ's, but this target has little impact on the costs and performance.

The target aggregate fill rate for regular replenishment orders at the RSHQ's should be 95%. This is compensated by a very high service level for emergency requested demand. There is no target needed for these emergency requests, since the costs for non-availability dominate the fill rate target.

10.2 Recommendations for Océ

At first, it is recommended to Océ to use the developed tool to *implement the new inventory control policy at the CSC and the RSHQ's* for parts in the regular phase of the life cycle. To make this implementation really successful it is important to:

- *Include all RSHQ's in S-CUBE*: an important strength of the model is that information of one echelon is used for the inventory control at the other echelon. It is recommended to include all RSHQ's in the model to make optimal use of this strength.
- *Register demand classes accurately*: the new inventory control policy differentiates between demands for regular replenishments and emergency requests. In order to set the right parameters for this policy the demand classes of every demand should be stored.
- *Store the dimensions of every part*: in order to make the right choice between sea- and air transportation, the dimensions of every part should be kept. It is recommended to use standard measures for this: m^3 and kgs.

The CSC and EMEA entities are currently carrying out a "carve out" project. The goal of the "carve out" project is to separate all CSC processes (business and financial) from the EMEA processes in the SAP system by creating a new enterprise structure, with companies and plants. Due to this split financial results can be linked to the CSC or EMEA. Pooling the inventories at the CSC for both entities, though, yields a 7% total cost decrease. Therefore it is strongly recommended to *pool the stocks at the CSC* as much as possible, despite that the business entities are split. The costs made at the CSC increase with this policy, but costs made at the RSHQ's decrease. For this reason, a solution has to be found to divide the financial gains over the locations.

The model's feature to determine the standard transportation mode per part has a high value. The costs are 35% lower if the choice is made for every part separately compared to the current practice, where sea transportation is used as the standard transportation mode. This leads to the strong recommendation to *use the tool to determine the standard transportation mode per part separately*.

Part of the designed inventory control policy is a critical level at all locations. The benefit of using this critical level is 2,5% at the CSC, but less than 0,5% at the RSHQ's. Therefore it is recommended to *implement the critical levels at the CSC* for sure. Implementing this into the information system of the RSHQ's has a lower priority.

Using the item classification based on 'part price' and 'average demand' has a positive impact on the system's performance. At the moment this is not yet possible to be used in the information system at the RSHQ's. Therefore it is recommended to *include the dimension 'price' in the GAIA-system* such that the benefits of the item classification can be achieved at the RSHQ's as well. Another solution could be to run the model outside GAIA and upload the found parameter settings into GAIA.

It is recommended to use the tool on a monthly basis in order to stay in track with the developments in demand patterns for parts and to reconsider the item classification on a regular basis, at least once every year.

In order to find the optimal item classification, it is recommended to Océ to further investigate whether improvements to the inventory control of spare parts can be made by improving the item classification. In this research a manual search for the optimal classification has been carried out, but in a follow-up project a more advanced method such as a greedy approach can be used. Furthermore, the option of always using an emergency shipment for very expensive slow movers can be examined.

With regards to the order size it is recommended to do a follow-up project in which the optimal order sizes are determined. The model developed in this research uses a standard order size of 1, but if another order size is determined, this does not affect the output in terms of the safety stock level of the part and its critical level.

10.3 Recommendations for future scientific research

Some complexities have arisen during this research that form opportunities for future research. One of these opportunities is to *find an approximation method for analyzing the single-echelon critical level policy with generally distributed demand*. Since especially for upstream locations the assumption that the demand follows a Poisson distribution may not always be valid, it is recommended to develop a method with general demand such as the model of Möllering and Thonemann (2008) which is practically applicable for real life cases where demand rates and lead times may be very large. An approximation method will be very useful to implement such a model in practice.

Another recommendation for future research is to *develop a multi-item model that uses heterogeneous customer classes*. The model of Enders et al. (2014) is a state-of-the-art model that makes use of heterogeneous customer classes, which means that for one class backordering is used, and for the other class emergency shipments can be requested. A model that uses this characteristic, which is based on the system approach, would be a further improvement on the work of Enders et al. (2014).

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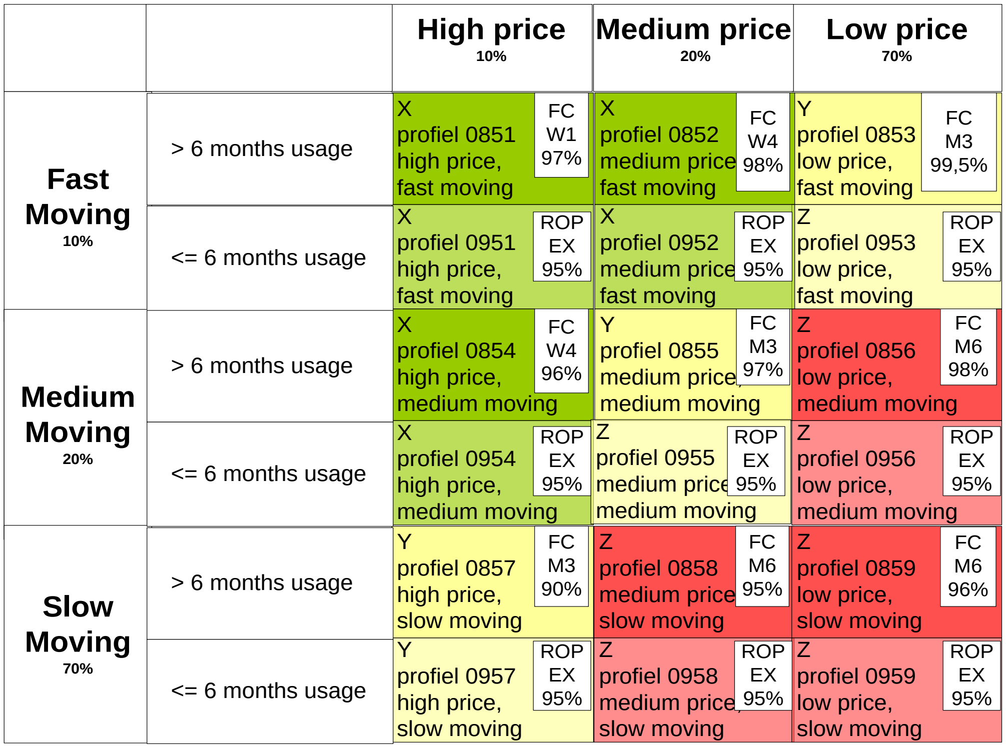
Appendix A All possible inbound and outbound flows

Location		Inbound Locations	Order type	Outbound Locations	Order Type
Suppliers				CSC	Regular
CSC		Suppliers	Regular		
				RSHQ	Regular
				RSHQ	Emergency
				National Warehouse	Emergency
				QRS	Emergency
				Car Stock	Emergency
				Customer	Emergency
RSHQ		CSC	Regular		
		CSC	Emergency		
				National Warehouse	Regular
				National Warehouse	Emergency
				QRS	Regular
				QRS	Emergency
				Car Stock	Regular
				Car Stock	Emergency
				Customer	Regular
				Customer	Emergency
				Dealers	Regular
National Warehouse		CSC	Emergency		
		RSHQ	Regular		
		RSHQ	Emergency		
				QRS	Regular
				QRS	Emergency
				Car Stock	Regular
				Car Stock	Emergency
				Customer	Regular
				Customer	Emergency
Field Stock Location	QRS	CSC	Emergency		
		RSHQ	Regular		
		RSHQ	Emergency		
		National Warehouse	Regular		
		National Warehouse	Emergency		
				Car Stock	Emergency
				Customer	Emergency
	Car Stock	CSC	Emergency		
		RSHQ	Regular		
		RSHQ	Emergency		
		National Warehouse	Regular		
		National Warehouse	Emergency		
		QRS	Emergency		
	Customer	CSC	Emergency		
		RSHQ	Regular		
		RSHQ	Emergency		
		National Warehouse	Regular		
		National Warehouse	Emergency		

Table 11.1: All possible order streams in the distribution network of Océ (shaded order streams are out of scope)

Appendix B XYZ-Classification

The following scheme is the basis of the item classification called XYZ. This method is currently used by SCM Service Parts 1 to control the inventories of spare parts at the CSC:



		High price 10%	**Medium price** 20%	**Low price** 70%
Fast Moving 10%	> 6 months usage	X profiel 0851 high price, fast moving FC W1 97%	X profiel 0852 medium price fast moving FC W4 98%	Y profiel 0853 low price, fast moving FC M3 99,5%
	<= 6 months usage	X profiel 0951 high price, fast moving ROP EX 95%	X profiel 0952 medium price fast moving ROP EX 95%	Z profiel 0953 low price, fast moving ROP EX 95%
Medium Moving 20%	> 6 months usage	X profiel 0854 high price, medium moving FC W4 96%	Y profiel 0855 medium price, medium moving FC M3 97%	Z profiel 0856 low price, medium moving FC M6 98%
	<= 6 months usage	X profiel 0954 high price, medium moving ROP EX 95%	Z profiel 0955 medium price medium moving ROP EX 95%	Z profiel 0956 low price, medium moving ROP EX 95%
Slow Moving 70%	> 6 months usage	Y profiel 0857 high price, slow moving FC M3 90%	Z profiel 0858 medium price slow moving FC M6 95%	Z profiel 0859 low price, slow moving FC M6 96%
	<= 6 months usage	Y profiel 0957 high price, slow moving ROP EX 95%	Z profiel 0958 medium price, slow moving ROP EX 95%	Z profiel 0959 low price, slow moving ROP EX 95%

Figure 11.1: XYZ-classification scheme

The XYZ-classification is based on the system approach. The idea of the system approach is to differentiate between parts, based on their characteristics, such that the aggregate service level constraints are met under lower cost than when all parts were control similarly. The XYZ method uses three dimensions: Price, Demand and Frequency. Price and Demand are used for frequently demanded parts to differentiate between the target service level and standard order quantity.

As can be seen from the figure, slow movers with a high price are controlled with a fill rate constraint of 90%, whereas fast moving, cheap items have a fill rate constraint of 99,5%. Aggregated, a fill rate constraint of 97% is met with this scheme. These different fill rates apply for items with a high demand frequency, which means that they were demanded in more than 6 months during the previous year.

Another item parameter that is controlled with the use of the classification scheme is the order quantity. As can be read from Figure 11.1, expensive fast movers have a standard order quantity that is equal to 1 week of demand (W1); cheap slow movers have a standard order quantity of 6 months of demand (M6)

For the parts with an infrequent demand pattern, Océ uses a reorder point (ROP) for the inventory control with an item fill rate constraint of 95%.

Appendix C Chi-squared test demand distribution

For both the CSC and the RSHQ in the USA (CUSA) the assumption that the demand follows a Poisson distribution is tested for nine parts with a chi-squared test. The following parts are selected such that of every category of the item classification one item is tested:

Part ID	Class
74	A1
97	A2
81	A3
89	B1
70	B2
41	B3
14	C1
36	C2
2	C3

Table 11.2: Parts used for test of Poisson distribution

In Table 11.3 and Table 11.4 the Chi-squared statistics can be found. The hypothesis that is tested is that the demand distribution of the part follows a Poisson distribution. As can be read from the tables this hypothesis is rejected for every test part except for two parts ($p < 0,05$). Therefore it is concluded that the demand distribution is not generally a Poisson distribution.

Part ID	Class	Chi-squared statistic
74	A1	0
97	A2	0
81	A3	0,043231583
89	B1	6,44111E-24
70	B2	0,99960614
41	B3	0
14	C1	0
36	C2	0
2	C3	0

Table 11.3: Chi-squared statistics for test parts at the RSHQ (CUSA)

Part ID	Class	Chi-squared statistic
74	A1	0
97	A2	0,002326985
81	A3	0,612946757
89	B1	0
70	B2	2,80619E-38
41	B3	8,4264E-26
14	C1	0
36	C2	0
2	C3	0

Table 11.4: Chi-squared statistics for test parts at the CSC

Appendix D Sub matrices of generator Q of Enders et al. (2014)

B_0 is an $(S+1) \times (S+1)$ matrix, which captures the transitions within level 0 of the Markov process. Let i and j be the matrix indices:

$$B_0(i,j) = \begin{cases} -(\lambda_2 + S\mu) & \text{if } i = j = 1; \\ -(\lambda + (S-i-1)\mu) & \text{if } 1 < i \leq S+1 \text{ and } j = i; \\ (S-i+1)\mu & \text{if } 1 \leq i < S+1 \text{ and } j = i+1; \\ \lambda_1 & \text{if } 1 < i \leq c+1 \text{ and } j = i-1; \\ \lambda & \text{if } c+1 < i \leq S+1 \text{ and } j = i-1; \\ 0 & \text{otherwise.} \end{cases}$$

B_{-1} is an $(c+1) \times (S+1)$ matrix, which captures the transition from level 1 to level 0:

$$B_{-1}(i,j) = \begin{cases} (S-c+1)\mu & \text{if } i = c+1 \text{ and } j = c+1; \\ 0 & \text{otherwise.} \end{cases}$$

B_1 is an $(S+1) \times (c+1)$ matrix, which captures the transitions from level 0 to level 1:

$$B_1(i,j) = \begin{cases} \lambda_2 & \text{if } 1 \leq i \leq c+1 \text{ and } j = i; \\ 0 & \text{otherwise.} \end{cases}$$

$A_0(n)$ is a $(c+1) \times (c+1)$ matrix, which describes the transitions within level n, for $n \geq 1$:

$$A_0(n)(i,j) = \begin{cases} -((S+n)\mu + \lambda_2) & \text{if } i = j = 1; \\ -((S+n-i+1)\mu + \lambda) & \text{if } 1 < i \leq c+1 \text{ and } j = i; \\ (S+n-i+1)\mu & \text{if } 1 \leq i < c+1 \text{ and } j = i+1; \\ \lambda_1 & \text{if } 1 < i \leq c+1 \text{ and } j = i-1; \\ 0 & \text{otherwise.} \end{cases}$$

$A_{-1}(n)$ is also a $(c+1) \times (c+1)$ matrix, which describes the transitions from level n to level $n-1$:

$$A_{-1}(n)(i,j) = \begin{cases} (S-c+n)\mu & \text{if } i = j = c+1; \\ 0 & \text{otherwise.} \end{cases}$$

A_1 is a $(c+1) \times (c+1)$ matrix as well, that describes the transitions form level n to level $n+1$:

$$A_1(i,j) = A_1(n)(i,j) = \begin{cases} \lambda_2 & \text{if } 1 \leq i \leq c+1 \text{ and } j = i; \\ 0 & \text{otherwise.} \end{cases}$$

Note that $A_1(n)$ is exactly the same for every level n, so the indicator (n) is omitted.

Appendix E Derivation of steady state formulas (Enders et al., 2014)

Q is the generator of the Markov process:

$$Q = \begin{pmatrix} B_0 & B_1 & 0 & 0 & 0 & \cdots \\ B_{-1} & A_0(1) & A_1 & 0 & 0 & \cdots \\ 0 & A_{-1}(2) & A_0(2) & A_1 & 0 & \cdots \\ 0 & 0 & A_{-1}(3) & A_0(3) & A_1 & \\ \vdots & \vdots & \ddots & \ddots & \ddots & \ddots \end{pmatrix}.$$

With the generator Q, the steady state vectors $\boldsymbol{\pi}_n$ can be calculated with the following system of equations:

$$\begin{aligned} \boldsymbol{\pi}_0 B_0 + \boldsymbol{\pi}_1 B_{-1} &= 0 && \text{for } n = 0 \\ \boldsymbol{\pi}_0 B_1 + \boldsymbol{\pi}_1 A_0(1) + \boldsymbol{\pi}_2 A_{-1}(2) &= 0 && \text{for } n = 1 \\ \boldsymbol{\pi}_{n-1} A_1 + \boldsymbol{\pi}_n A_0(n) + \boldsymbol{\pi}_{n+1} A_{-1}(n+1) &= 0 && \text{for } n \geq 2 \\ \sum_{n=0}^{\infty} \boldsymbol{\pi}_n \boldsymbol{e} &= 1, \end{aligned}$$

where $\boldsymbol{e}$ is the vector of ones of the appropriate size. Because this system cannot be solved, Enders et al. (2014) have found a solution that depends on the following system of equations:

$$\begin{aligned} \tilde{\boldsymbol{\pi}}_0 B_0 + \tilde{\boldsymbol{\pi}}_1 B_{-1} &= 0 && \text{for } n = 0 \\ \tilde{\boldsymbol{\pi}}_0 B_1 + \tilde{\boldsymbol{\pi}}_1 A_0(1) + \tilde{\boldsymbol{\pi}}_2 A_{-1}(2) &= 0 && \text{for } n = 1 \\ \tilde{\boldsymbol{\pi}}_{n-1} A_1 + \tilde{\boldsymbol{\pi}}_n A_0(n) + \tilde{\boldsymbol{\pi}}_{n+1} A_{-1}(n+1) &= 0 && \text{for } n \geq 2 \\ \tilde{\pi}_{S,0} &= 1. \end{aligned}$$

For $n \geq 1$ the third term of the left-hand side of the second and third equation can be written as:

$$\tilde{\boldsymbol{\pi}}_{n+1} A_{-1}(n+1) = \left(0, \ldots, 0, \tilde{\pi}_{c,n+1}(S - c + n + 1)\mu\right).$$

Because backorders can only be cleared (i.e.: a transition of level $n+1$ to level n) from $(c, n+1)$ to (c, n) in steady state, the following equation holds:

$$\tilde{\pi}_{c,n+1}(S - c + n + 1)\mu = \tilde{\boldsymbol{\pi}}_n A_1 \boldsymbol{e} = \lambda_2 \tilde{\boldsymbol{\pi}}_n \boldsymbol{e},$$

Combining the last two equations leads to:

$$\tilde{\boldsymbol{\pi}}_{n+1} A_{-1}(n+1) = \lambda_2 \tilde{\boldsymbol{\pi}}_n A,$$

where A is defined in (20). The system of equations can now be rewritten:

$$\begin{aligned} \tilde{\boldsymbol{\pi}}_0 B_0 + \tilde{\boldsymbol{\pi}}_1 B_{-1} &= 0 && \text{for } n = 0 \\ \tilde{\boldsymbol{\pi}}_0 B_1 + \tilde{\boldsymbol{\pi}}_1 A_0(1) + \lambda_2 \tilde{\boldsymbol{\pi}}_1 A &= 0 && \text{for } n = 1 \\ \tilde{\boldsymbol{\pi}}_{n-1} A_1 + \tilde{\boldsymbol{\pi}}_n A_0(n) + \lambda_2 \tilde{\boldsymbol{\pi}}_n A &= 0 && \text{for } n \geq 2 \\ \tilde{\pi}_{S,0} &= 1. \end{aligned}$$

With the first, second and fourth of these equations, $\tilde{\boldsymbol{\pi}}_0$ and $\tilde{\boldsymbol{\pi}}_1$ can be obtained. The third equation can be rewritten as:

$$\tilde{\boldsymbol{\pi}}_n = -\tilde{\boldsymbol{\pi}}_{n-1} A_1 (A_0(n) + A\lambda_2)^{-1} \quad \text{for } n \geq 2,$$

Which can be used to recursively calculate the vectors $\tilde{\boldsymbol{\pi}}_n$ for $n \geq 2$. In order for the steady state probabilities to sum up to 1, the vectors $\tilde{\boldsymbol{\pi}}_n$ need to be renormalized with the following equation:

$$\boldsymbol{\pi}_n = \frac{\tilde{\boldsymbol{\pi}}_n}{\sum_{n=0}^{\infty} \tilde{\boldsymbol{\pi}}_n \boldsymbol{e}}.$$

Appendix F Derivation of the bounding function of Enders et al. (2014)

The bounding function is based on diagonal levels for $n \geq 0$: $\{(0,n),(1,n+1),\dots,(c,n+c)\}$ and the corresponding probability vectors $\widetilde{\boldsymbol{\delta}}_n = (\tilde{\pi}_{0,n}, \tilde{\pi}_{1,n+1}, \dots, \tilde{\pi}_{c,n+c})$. The balance equation between two subsequent diagonal levels is the following:

$$\widetilde{\boldsymbol{\delta}}_n \boldsymbol{e}\lambda - \tilde{\pi}_{0,n}\lambda_1 = \widetilde{\boldsymbol{\delta}}_{n+1}\boldsymbol{e}(S+n+1)\mu,$$

so the following inequality can be derived:

$$\widetilde{\boldsymbol{\delta}}_n \boldsymbol{e}\lambda \geq \widetilde{\boldsymbol{\delta}}_{n+1}\boldsymbol{e}(S+n+1)\mu.$$

The probability of being at diagonal level $n+1$ can now be expressed as follows:

$$\widetilde{\boldsymbol{\delta}}_{n+1}\boldsymbol{e} \leq \frac{\lambda}{\mu}\frac{1}{S+n+1}\widetilde{\boldsymbol{\delta}}_n \boldsymbol{e}.$$

Enders et al. (2014) introduce a cutoff parameter $\ell \geq 1$ to bound the weighted probabilities of the horizontal levels $\widetilde{\boldsymbol{\pi}}_n$. Since the probability mass decreases when the level increases and the lowest diagonal layer includes states below the lowest horizontal bounding level, the diagonal levels can be used to bound the weighted steady state probabilities:

$$\begin{aligned}\sum_{n=c+\ell}^{\infty} n\widetilde{\boldsymbol{\pi}}_n \boldsymbol{e} \quad &\leq \sum_{n=\ell}^{\infty}(n+c)\widetilde{\boldsymbol{\delta}}_n \boldsymbol{e} \\ &= \sum_{k=0}^{\infty}(k+\ell+c)\widetilde{\boldsymbol{\delta}}_{\ell+k}\boldsymbol{e}\,.\end{aligned}$$

With the recursive use of the relation between two subsequent diagonal levels, the following relation is found for two diagonal levels at distance k:

$$\begin{aligned}\widetilde{\boldsymbol{\delta}}_{\ell+k}\boldsymbol{e} \quad &\leq \left(\frac{\lambda}{\mu}\right)^k \frac{1}{(S+\ell+k)\dots(S+\ell+1)}\widetilde{\boldsymbol{\delta}}_\ell \boldsymbol{e} \\ &= \left(\frac{\lambda}{\mu}\right)^k \frac{(S+\ell)!}{(S+\ell+k)!}\widetilde{\boldsymbol{\delta}}_\ell \boldsymbol{e}.\end{aligned}$$

Now this relation can be used further derive a function to bound $\sum_{n=c+\ell}^{\infty} n\widetilde{\boldsymbol{\pi}}_n \boldsymbol{e}$:

$$\begin{aligned}\sum_{n=c+\ell}^{\infty} n\widetilde{\boldsymbol{\pi}}_n\boldsymbol{e} &\le \sum_{k=0}^{\infty}\left(\frac{\lambda}{\mu}\right)^k \frac{(S+\ell)!}{(S+\ell+k)!}\widetilde{\boldsymbol{\delta}}_\ell\boldsymbol{e}(k+\ell+c)\\ &= \widetilde{\boldsymbol{\delta}}_\ell\boldsymbol{e}(S+\ell)!\left(\frac{\mu}{\lambda}\right)^{S+\ell}\left[\sum_{k=0}^{\infty}\left(\frac{\lambda}{\mu}\right)^{S+\ell+k}\frac{1}{(S+\ell+k)!}(k+\ell+c)\right]\\ &= \widetilde{\boldsymbol{\delta}}_\ell\boldsymbol{e}(S+\ell)!\left(\frac{\mu}{\lambda}\right)^{S+\ell}\left[\sum_{k=0}^{\infty}\left(\frac{\lambda}{\mu}\right)^{S+\ell+k}\frac{1}{(S+\ell+k)!}(k+S+\ell)\right.\\ &\left.-(S-c)\sum_{k=0}^{\infty}\left(\frac{\lambda}{\mu}\right)^{S+\ell+k}\frac{1}{(S+\ell+k)!}\right].\end{aligned}$$

In order for this relationship to be more convenient, the following function is used:

$$\phi(\ell) = \sum_{k=\ell}^{\infty}\left(\frac{\lambda}{\mu}\right)^k \frac{1}{k!} = e^{\frac{\lambda}{\mu}} - \sum_{k=0}^{\ell-1}\left(\frac{\lambda}{\mu}\right)^k \frac{1}{k!}.$$

So the derivation finally comes to:

$\sum_{n=c+\ell}^{\infty} n\widetilde{\boldsymbol{\pi}}_n\boldsymbol{e} \le \widetilde{\boldsymbol{\delta}}_\ell\boldsymbol{e}(S+\ell)!\left(\frac{\mu}{\lambda}\right)^{S+\ell}\left[\frac{\lambda}{\mu}\phi(S+\ell-1)-(S-c)\phi(S+\ell)\right].$

Appendix G Data set

Part Nr. (ID)	Lead time (days)	h (€/year)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
1	28	1,354	28,657	1	97,00%	82,40%
2	84	0,066	32,428	1	97,00%	82,40%
3	84	0,068	22,624	1	97,00%	82,40%
4	126	0,062	46,002	1	97,00%	82,40%
5	14	0,002	20605,909	1	99,90%	84,86%
6	7	0,002	94,267	1	97,00%	82,40%
7	3	4,662	2,262	1	97,00%	82,40%
8	112	0,102	0,754	1	97,00%	82,40%
9	3	0,638	109,349	1	98,50%	83,67%
10	151	0,774	6,787	1	97,00%	82,40%
11	91	0,058	98,791	1	97,00%	82,40%
12	170	0,474	921,550	1	99,90%	84,86%
13	106	0,590	1,508	1	97,00%	82,40%
14	112	0,090	1749,587	1	99,90%	84,86%
15	230	0,600	67,872	1	97,00%	82,40%
16	253	1,078	44,494	1	97,00%	82,40%
17	133	0,632	142,531	1	98,50%	83,67%
18	3	3,792	88,988	1	97,00%	82,40%
19	177	2,418	21,870	1	97,00%	82,40%
20	161	2,772	7,541	1	97,00%	82,40%
21	88	0,058	24,132	1	97,00%	82,40%
22	56	0,446	7,541	1	97,00%	82,40%
23	145	2,516	5,279	1	97,00%	82,40%
24	14	0,248	13,574	1	97,00%	82,40%
25	14	0,860	1,508	1	97,00%	82,40%
26	98	0,124	83,709	1	97,00%	82,40%
27	161	2,748	16,591	1	97,00%	82,40%
28	121	2,782	30,165	1	97,00%	82,40%
29	3	0,002	37,707	1	97,00%	82,40%
30	14	0,794	17,345	1	97,00%	82,40%
31	150	2,214	112,366	1	98,50%	83,67%
32	140	3,120	125,186	1	98,50%	83,67%
33	84	3,124	8,295	1	97,00%	82,40%
34	3	0,164	757,149	1	99,90%	84,86%
35	99	0,138	4,525	1	97,00%	82,40%
36	182	0,124	172,696	1	98,50%	83,67%
37	99	2,638	9,050	1	97,00%	82,40%
38	35	0,794	385,362	1	98,50%	83,67%
39	191	23,768	35,444	1	92,00%	78,15%
40	91	0,028	15,837	1	97,00%	82,40%
41	69	5,842	40,723	1	92,00%	78,15%
42	175	3,298	806,921	1	99,90%	84,86%
43	98	0,046	77,676	1	97,00%	82,40%
44	83	0,190	9,804	1	97,00%	82,40%
45	253	1,528	68,626	1	97,00%	82,40%
46	3	11,058	113,874	1	97,00%	82,40%
47	217	5,516	12,820	1	92,00%	78,15%
48	84	3,166	9,050	1	97,00%	82,40%
49	57	0,066	8,295	1	97,00%	82,40%
50	133	0,076	9,804	1	97,00%	82,40%
51	84	0,682	131,219	1	98,50%	83,67%
52	84	5,712	7,541	1	92,00%	78,15%
53	3	10,476	38,461	1	92,00%	78,15%
54	189	0,814	14,329	1	97,00%	82,40%
55	28	0,336	5,279	1	97,00%	82,40%
56	115	0,278	0,000	1	97,00%	82,40%
57	119	1,494	104,824	1	97,00%	82,40%

Part Nr. (ID)	Lead time (CSC)	h (CSC)	Demand rate/year	Fraction Class 1	Fill rate (Class 1)	Fill rate (Class 2)
58	147	0,112	623,667	1	98,50%	83,67%
59	427	33,712	112,366	1	94,00%	79,85%
60	70	0,238	3,017	1	97,00%	82,40%
61	0	2,376	3,771	1	97,00%	82,40%
62	3	3,350	22,624	1	97,00%	82,40%
63	141	0,150	39,969	1	97,00%	82,40%
64	42	0,056	1063,326	1	99,90%	84,86%
65	98	3,454	9,804	1	97,00%	82,40%
66	289	6,288	18,853	1	92,00%	78,15%
67	223	0,700	255,651	1	98,50%	83,67%
68	3	0,280	345,393	1	98,50%	83,67%
69	21	9,350	30,165	1	92,00%	78,15%
70	3	8,764	134,990	1	97,00%	82,40%
71	42	1,558	26,395	1	97,00%	82,40%
72	42	0,038	35,444	1	97,00%	82,40%
73	3	10,720	115,382	1	97,00%	82,40%
74	7	151,952	4948,616	1	96,00%	81,55%
75	28	15,112	65,610	1	92,00%	78,15%
76	114	2,242	150,826	1	98,50%	83,67%
77	133	0,310	343,130	1	98,50%	83,67%
78	35	0,258	1,508	1	97,00%	82,40%
79	77	5,850	36,198	1	92,00%	78,15%
80	253	8,994	169,680	1	97,00%	82,40%
81	428	30,294	54,298	1	82,40%	70,00%
82	121	6,806	11,312	1	92,00%	78,15%
83	3	0,426	2,262	1	97,00%	82,40%
84	231	13,992	90,496	1	92,00%	78,15%
85	56	1,116	5,279	1	97,00%	82,40%
86	161	0,494	854,432	1	99,90%	84,86%
87	94	0,242	24,132	1	97,00%	82,40%
88	77	0,566	27,149	1	97,00%	82,40%
89	175	5,124	651,570	1	98,00%	83,25%
90	135	9,048	134,236	1	97,00%	82,40%
91	105	1,288	322,769	1	98,50%	83,67%
92	288	21,862	64,855	1	92,00%	78,15%
93	274	19,820	73,905	1	92,00%	78,15%
94	147	2,644	88,233	1	97,00%	82,40%
95	84	1,044	11,312	1	97,00%	82,40%
96	42	2,400	0,754	1	97,00%	82,40%
97	3	39,258	287,324	1	94,00%	79,85%
98	126	3,486	18,099	1	97,00%	82,40%
99	217	13,958	448,709	1	97,00%	82,40%
100	245	29,288	30,165	1	92,00%	78,15%
101	224	30,842	147,810	1	94,00%	79,85%
102	274	4,064	89,742	1	97,00%	82,40%
103	442	25,530	625,930	1	98,00%	83,25%
104	56	4,200	107,087	1	97,00%	82,40%
105	266	85,266	76,167	1	82,40%	70,00%
106	260	65,124	88,988	1	82,40%	70,00%
107	7	96,866	1101,787	1	96,00%	81,55%
108	7	96,738	49,773	1	82,40%	70,00%
109	7	96,746	45,248	1	82,40%	70,00%
110	176	31,526	7,541	1	82,40%	70,00%
111	3	12,000	330,310	1	97,00%	82,40%
112	28	0,310	0,000	1	97,00%	82,40%

Table 11.5: Data set used for the CSC

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
1	42	14	1,354	0,253	1,260	0,000	0,500	0,00%	95,00%
2	42	14	0,066	0,001	0,005	55,052	0,329	0,00%	95,00%
3	42	14	0,068	0,001	0,005	0,000	0,500	0,00%	95,00%
4	42	14	0,062	0,001	0,009	35,444	0,681	0,00%	95,00%
5	42	14	0,002	0,009	1,066	0,000	0,500	0,00%	97,84%
6	42	14	0,002	0,001	0,005	116,136	0,351	0,00%	95,00%
7	42	14	4,662	0,017	1,418	0,000	0,500	0,00%	95,00%
8	42	14	0,102	0,001	0,009	3,771	0,600	0,00%	95,00%
9	42	14	0,638	0,004	0,360	6,787	0,889	0,00%	96,47%
10	42	14	0,774	0,143	0,288	39,215	0,385	0,00%	95,00%
11	42	14	0,058	0,004	0,009	33,182	0,500	0,00%	95,00%
12	42	14	0,474	0,000	0,031	82,200	0,642	0,00%	97,84%
13	42	14	0,590	0,082	1,665	1,508	0,000	0,00%	95,00%
14	42	14	0,090	0,001	0,045	468,316	0,546	0,00%	97,84%
15	42	14	0,600	0,001	0,032	11,312	0,333	0,00%	95,00%
16	42	14	1,078	0,053	0,207	7,541	1,000	0,00%	95,00%
17	42	14	0,632	0,015	0,257	19,607	0,923	0,00%	96,47%
18	42	14	3,792	0,024	0,099	12,066	0,813	0,00%	95,00%
19	42	14	2,418	0,436	1,350	5,279	0,714	0,00%	95,00%
20	42	14	2,772	0,024	1,611	7,541	0,900	0,00%	95,00%
21	42	14	0,058	0,001	0,014	5,279	1,000	0,00%	95,00%
22	42	14	0,446	0,001	0,005	0,000	0,500	0,00%	95,00%
23	42	14	2,516	0,082	0,801	2,262	1,000	0,00%	95,00%
24	42	14	0,248	0,001	0,014	6,033	0,000	0,00%	95,00%
25	42	14	0,860	0,082	0,023	0,000	0,500	0,00%	95,00%
26	42	14	0,124	0,006	0,149	14,329	0,421	0,00%	95,00%
27	42	14	2,748	0,051	0,045	16,591	0,955	0,00%	95,00%
28	42	14	2,782	0,082	7,101	2,262	1,000	0,00%	95,00%
29	42	14	0,002	0,001	0,009	0,000	0,500	0,00%	95,00%
30	42	14	0,794	0,001	0,081	39,969	0,396	0,00%	95,00%
31	42	14	2,214	0,001	0,113	20,362	0,778	0,00%	96,47%
32	42	14	3,120	0,001	0,113	18,099	0,458	0,00%	96,47%
33	42	14	3,124	0,137	0,954	6,033	0,875	0,00%	95,00%
34	42	14	0,164	0,017	0,086	242,076	0,489	0,00%	97,84%
35	42	14	0,138	0,082	2,430	1,508	1,000	0,00%	95,00%
36	42	14	0,124	0,082	0,086	31,674	0,381	0,00%	96,47%
37	42	14	2,638	0,009	0,909	2,262	0,667	0,00%	95,00%
38	42	14	0,794	0,123	0,022	162,893	0,463	0,00%	96,47%
39	42	14	23,768	0,082	12,645	3,017	0,500	0,00%	90,10%
40	42	14	0,028	0,001	0,450	9,050	0,417	0,00%	95,00%
41	42	14	5,842	0,202	0,360	14,329	0,684	0,00%	90,10%
42	42	14	3,298	0,002	0,135	80,692	0,710	0,00%	97,84%
43	42	14	0,046	0,001	0,036	37,707	0,280	0,00%	95,00%
44	42	14	0,190	0,082	0,077	3,771	0,000	0,00%	95,00%
45	42	14	1,528	0,082	4,500	3,771	0,600	0,00%	95,00%
46	42	14	11,058	0,202	4,158	7,541	0,300	0,00%	95,00%
47	42	14	5,516	0,082	10,350	5,279	0,571	0,00%	90,10%
48	42	14	3,166	0,051	1,584	0,000	0,500	0,00%	95,00%
49	42	14	0,066	0,001	0,009	0,000	0,500	0,00%	95,00%
50	42	14	0,076	0,001	0,014	3,771	0,200	0,00%	95,00%
51	42	14	0,682	0,002	0,450	28,657	0,421	0,00%	96,47%
52	42	14	5,712	0,082	4,500	0,754	1,000	0,00%	90,10%
53	42	14	10,476	0,267	4,829	5,279	0,857	0,00%	90,10%
54	42	14	0,814	0,002	0,527	6,787	0,000	0,00%	95,00%
55	42	14	0,336	0,123	0,014	0,000	0,500	0,00%	95,00%
56	42	14	0,278	0,082	0,003	5,279	1,000	0,00%	95,00%
57	42	14	1,494	0,123	0,113	37,707	0,540	0,00%	95,00%
58	42	14	0,112	0,004	0,045	190,041	0,532	0,00%	96,47%

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
59	42	14	33,712	1,079	7,389	19,607	0,731	0,00%	92,06%
60	42	14	0,238	0,030	0,023	0,000	0,500	0,00%	95,00%
61	42	14	2,376	0,082	2,250	2,262	1,000	0,00%	95,00%
62	42	14	3,350	0,013	0,207	6,787	0,444	0,00%	95,00%
63	42	14	0,150	0,001	0,005	5,279	0,857	0,00%	95,00%
64	42	14	0,056	0,001	0,067	196,074	0,577	0,00%	97,84%
65	42	14	3,454	0,002	0,468	1,508	1,000	0,00%	95,00%
66	42	14	6,288	0,141	0,900	9,050	0,750	0,00%	90,10%
67	42	14	0,700	0,001	0,040	63,347	0,464	0,00%	96,47%
68	42	14	0,280	0,082	0,225	7,541	0,700	0,00%	96,47%
69	42	14	9,350	0,009	0,450	0,000	0,500	0,00%	90,10%
70	42	14	8,764	0,436	7,200	22,624	0,633	0,00%	95,00%
71	42	14	1,558	0,001	0,270	12,066	0,688	0,00%	95,00%
72	42	14	0,038	0,001	0,023	8,295	0,909	0,00%	95,00%
73	42	14	10,720	2,521	10,800	34,690	0,478	0,00%	95,00%
74	42	14	151,952	0,257	2,250	1406,457	0,458	0,00%	94,02%
75	42	14	15,112	0,139	0,450	5,279	0,714	0,00%	90,10%
76	42	14	2,242	0,006	0,464	54,298	0,583	0,00%	96,47%
77	42	14	0,310	0,001	0,027	28,657	0,868	0,00%	96,47%
78	42	14	0,258	0,123	0,495	1,508	0,000	0,00%	95,00%
79	42	14	5,850	0,082	3,668	2,262	0,667	0,00%	90,10%
80	42	14	8,994	0,082	4,230	27,903	0,703	0,00%	95,00%
81	42	14	30,294	0,082	0,450	5,279	1,000	0,00%	80,70%
82	42	14	6,806	0,082	0,752	4,525	0,667	0,00%	90,10%
83	42	14	0,426	0,082	0,315	0,000	0,500	0,00%	95,00%
84	42	14	13,992	0,082	5,400	15,083	0,750	0,00%	90,10%
85	42	14	1,116	0,082	0,095	1,508	1,000	0,00%	95,00%
86	42	14	0,494	0,001	0,450	169,680	0,187	0,00%	97,84%
87	42	14	0,242	0,001	0,450	31,674	0,667	0,00%	95,00%
88	42	14	0,566	0,123	0,450	9,804	0,615	0,00%	95,00%
89	42	14	5,124	0,082	2,250	101,054	0,627	0,00%	95,98%
90	42	14	9,048	0,873	6,750	31,674	0,786	0,00%	95,00%
91	42	14	1,288	0,006	0,185	79,938	0,594	0,00%	96,47%
92	42	14	21,862	0,082	1,800	6,033	0,625	0,00%	90,10%
93	42	14	19,820	0,082	1,467	9,050	0,833	0,00%	90,10%
94	42	14	2,644	0,082	4,172	21,870	0,517	0,00%	95,00%
95	42	14	1,044	0,141	0,720	1,508	0,500	0,00%	95,00%
96	42	14	2,400	0,033	0,113	0,754	0,000	0,00%	95,00%
97	42	14	39,258	0,082	2,880	65,610	0,701	0,00%	92,06%
98	42	14	3,486	0,082	0,360	0,000	0,500	0,00%	95,00%
99	42	14	13,958	0,082	9,000	110,103	0,712	0,00%	95,00%
100	42	14	29,288	0,082	29,250	12,066	0,875	0,00%	90,10%
101	42	14	30,842	0,082	23,850	11,312	0,933	0,00%	92,06%
102	42	14	4,064	0,082	0,509	37,707	0,780	0,00%	95,00%
103	42	14	25,530	0,082	11,700	193,058	0,609	0,00%	95,98%
104	42	14	4,200	0,082	0,833	404,969	0,469	0,00%	95,00%
105	42	14	85,266	0,082	13,500	1,508	1,000	0,00%	80,70%
106	42	14	65,124	0,082	38,250	8,295	0,818	0,00%	80,70%
107	42	14	96,866	0,082	2,399	0,000	0,500	0,00%	94,02%
108	42	14	96,738	0,082	2,250	0,000	0,500	0,00%	80,70%
109	42	14	96,746	0,082	2,250	0,000	0,500	0,00%	80,70%
110	42	14	31,526	22,797	90,000	1,508	0,000	0,00%	80,70%
111	42	14	12,000	1,065	5,400	230,764	0,007	0,00%	95,00%
112	42	14	0,310	0,082	0,003	8,295	1,000	0,00%	95,00%

Table 11.6: Data set used for RSHQ 1

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
1	45	14	1,354	0,128	1,260	18,853	0,500	0,00%	95,00%
2	45	14	0,066	0,001	0,005	0,000	0,329	0,00%	95,00%
3	45	14	0,068	0,001	0,005	0,000	0,500	0,00%	95,00%
4	45	14	0,062	0,001	0,009	0,754	0,681	0,00%	95,00%
5	45	14	0,002	0,004	1,066	0,000	0,500	0,00%	97,84%
6	45	14	0,002	0,001	0,005	0,000	0,351	0,00%	95,00%
7	45	14	4,662	0,008	1,418	0,000	0,500	0,00%	95,00%
8	45	14	0,102	0,001	0,009	0,000	0,600	0,00%	95,00%
9	45	14	0,638	0,002	0,360	0,000	0,889	0,00%	96,47%
10	45	14	0,774	0,072	0,288	0,000	0,385	0,00%	95,00%
11	45	14	0,058	0,002	0,009	0,000	0,500	0,00%	95,00%
12	45	14	0,474	0,000	0,031	16,591	0,642	0,00%	97,84%
13	45	14	0,590	0,041	1,665	0,000	0,000	0,00%	95,00%
14	45	14	0,090	0,001	0,045	30,165	0,546	0,00%	97,84%
15	45	14	0,600	0,000	0,032	0,754	0,333	0,00%	95,00%
16	45	14	1,078	0,026	0,207	0,754	1,000	0,00%	95,00%
17	45	14	0,632	0,007	0,257	0,000	0,923	0,00%	96,47%
18	45	14	3,792	0,012	0,099	1,508	0,813	0,00%	95,00%
19	45	14	2,418	0,219	1,350	1,508	0,714	0,00%	95,00%
20	45	14	2,772	0,012	1,611	0,000	0,900	0,00%	95,00%
21	45	14	0,058	0,000	0,014	0,000	1,000	0,00%	95,00%
22	45	14	0,446	0,000	0,005	0,000	0,500	0,00%	95,00%
23	45	14	2,516	0,041	0,801	1,508	1,000	0,00%	95,00%
24	45	14	0,248	0,000	0,014	0,000	0,000	0,00%	95,00%
25	45	14	0,860	0,041	0,023	0,000	0,500	0,00%	95,00%
26	45	14	0,124	0,003	0,149	0,000	0,421	0,00%	95,00%
27	45	14	2,748	0,026	0,045	1,508	0,955	0,00%	95,00%
28	45	14	2,782	0,041	7,101	0,000	1,000	0,00%	95,00%
29	45	14	0,002	0,001	0,009	0,000	0,500	0,00%	95,00%
30	45	14	0,794	0,001	0,081	3,017	0,396	0,00%	95,00%
31	45	14	2,214	0,001	0,113	1,508	0,778	0,00%	96,47%
32	45	14	3,120	0,001	0,113	0,754	0,458	0,00%	96,47%
33	45	14	3,124	0,069	0,954	0,754	0,875	0,00%	95,00%
34	45	14	0,164	0,009	0,086	26,395	0,489	0,00%	97,84%
35	45	14	0,138	0,041	2,430	0,000	1,000	0,00%	95,00%
36	45	14	0,124	0,041	0,086	1,508	0,381	0,00%	96,47%
37	45	14	2,638	0,004	0,909	0,000	0,667	0,00%	95,00%
38	45	14	0,794	0,062	0,022	7,541	0,463	0,00%	96,47%
39	45	14	23,768	0,041	12,645	0,000	0,500	0,00%	90,10%
40	45	14	0,028	0,001	0,450	0,000	0,417	0,00%	95,00%
41	45	14	5,842	0,102	0,360	0,000	0,684	0,00%	90,10%
42	45	14	3,298	0,001	0,135	14,329	0,710	0,00%	97,84%
43	45	14	0,046	0,001	0,036	1,508	0,280	0,00%	95,00%
44	45	14	0,190	0,041	0,077	0,000	0,000	0,00%	95,00%
45	45	14	1,528	0,041	4,500	0,754	0,600	0,00%	95,00%
46	45	14	11,058	0,102	4,158	1,508	0,300	0,00%	95,00%
47	45	14	5,516	0,041	10,350	3,017	0,571	0,00%	90,10%
48	45	14	3,166	0,026	1,584	0,754	0,500	0,00%	95,00%
49	45	14	0,066	0,000	0,009	0,000	0,500	0,00%	95,00%
50	45	14	0,076	0,000	0,014	0,000	0,200	0,00%	95,00%
51	45	14	0,682	0,001	0,450	3,017	0,421	0,00%	96,47%
52	45	14	5,712	0,041	4,500	0,000	1,000	0,00%	90,10%
53	45	14	10,476	0,135	4,829	0,754	0,857	0,00%	90,10%
54	45	14	0,814	0,001	0,527	0,000	0,000	0,00%	95,00%
55	45	14	0,336	0,062	0,014	0,000	0,500	0,00%	95,00%
56	45	14	0,278	0,041	0,003	0,000	1,000	0,00%	95,00%
57	45	14	1,494	0,062	0,113	3,771	0,540	0,00%	95,00%
58	45	14	0,112	0,002	0,045	9,804	0,532	0,00%	96,47%

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
59	45	14	33,712	0,543	7,389	5,279	0,731	0,00%	92,06%
60	45	14	0,238	0,015	0,023	0,000	0,500	0,00%	95,00%
61	45	14	2,376	0,041	2,250	0,000	1,000	0,00%	95,00%
62	45	14	3,350	0,007	0,207	3,017	0,444	0,00%	95,00%
63	45	14	0,150	0,001	0,005	0,000	0,857	0,00%	95,00%
64	45	14	0,056	0,001	0,067	7,541	0,577	0,00%	97,84%
65	45	14	3,454	0,001	0,468	0,000	1,000	0,00%	95,00%
66	45	14	6,288	0,071	0,900	0,000	0,750	0,00%	90,10%
67	45	14	0,700	0,000	0,040	1,508	0,464	0,00%	96,47%
68	45	14	0,280	0,041	0,225	2,262	0,700	0,00%	96,47%
69	45	14	9,350	0,004	0,450	0,754	0,500	0,00%	90,10%
70	45	14	8,764	0,219	7,200	2,262	0,633	0,00%	95,00%
71	45	14	1,558	0,001	0,270	0,000	0,688	0,00%	95,00%
72	45	14	0,038	0,001	0,023	0,000	0,909	0,00%	95,00%
73	45	14	10,720	1,270	10,800	5,279	0,478	0,00%	95,00%
74	45	14	151,952	0,129	2,250	150,072	0,458	0,00%	94,02%
75	45	14	15,112	0,070	0,450	12,066	0,714	0,00%	90,10%
76	45	14	2,242	0,003	0,464	3,017	0,583	0,00%	96,47%
77	45	14	0,310	0,001	0,027	4,525	0,868	0,00%	96,47%
78	45	14	0,258	0,062	0,495	0,000	0,000	0,00%	95,00%
79	45	14	5,850	0,041	3,668	0,754	0,667	0,00%	90,10%
80	45	14	8,994	0,041	4,230	2,262	0,703	0,00%	95,00%
81	45	14	30,294	0,041	0,450	1,508	1,000	0,00%	80,70%
82	45	14	6,806	0,041	0,752	0,754	0,667	0,00%	90,10%
83	45	14	0,426	0,041	0,315	0,000	0,500	0,00%	95,00%
84	45	14	13,992	0,041	5,400	0,000	0,750	0,00%	90,10%
85	45	14	1,116	0,041	0,095	0,000	1,000	0,00%	95,00%
86	45	14	0,494	0,001	0,450	15,837	0,187	0,00%	97,84%
87	45	14	0,242	0,001	0,450	0,000	0,667	0,00%	95,00%
88	45	14	0,566	0,062	0,450	0,000	0,615	0,00%	95,00%
89	45	14	5,124	0,041	2,250	12,820	0,627	0,00%	95,98%
90	45	14	9,048	0,440	6,750	1,508	0,786	0,00%	95,00%
91	45	14	1,288	0,003	0,185	5,279	0,594	0,00%	96,47%
92	45	14	21,862	0,041	1,800	2,262	0,625	0,00%	90,10%
93	45	14	19,820	0,041	1,467	0,000	0,833	0,00%	90,10%
94	45	14	2,644	0,041	4,172	0,754	0,517	0,00%	95,00%
95	45	14	1,044	0,071	0,720	0,000	0,500	0,00%	95,00%
96	45	14	2,400	0,017	0,113	0,000	0,000	0,00%	95,00%
97	45	14	39,258	0,041	2,880	3,771	0,701	0,00%	92,06%
98	45	14	3,486	0,041	0,360	0,000	0,500	0,00%	95,00%
99	45	14	13,958	0,041	9,000	12,820	0,712	0,00%	95,00%
100	45	14	29,288	0,041	29,250	0,754	0,875	0,00%	90,10%
101	45	14	30,842	0,041	23,850	0,000	0,933	0,00%	92,06%
102	45	14	4,064	0,041	0,509	1,508	0,780	0,00%	95,00%
103	45	14	25,530	0,041	11,700	24,132	0,609	0,00%	95,98%
104	45	14	4,200	0,041	0,833	87,479	0,469	0,00%	95,00%
105	45	14	85,266	0,041	13,500	1,508	1,000	0,00%	80,70%
106	45	14	65,124	0,041	38,250	1,508	0,818	0,00%	80,70%
107	45	14	96,866	0,041	2,399	0,000	0,500	0,00%	94,02%
108	45	14	96,738	0,041	2,250	0,000	0,500	0,00%	80,70%
109	45	14	96,746	0,041	2,250	0,000	0,500	0,00%	80,70%
110	45	14	31,526	11,482	90,000	0,000	0,000	0,00%	80,70%
111	45	14	12,000	0,536	5,400	18,853	0,007	0,00%	95,00%
112	45	14	0,310	0,041	0,003	0,000	1,000	0,00%	95,00%

Table 11.7: Data set used for RSHQ 2

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
1	50	14	1,354	0,253	1,260	0,754	0,500	0,00%	95,00%
2	50	14	0,066	0,001	0,005	0,000	0,329	0,00%	95,00%
3	50	14	0,068	0,001	0,005	0,000	0,500	0,00%	95,00%
4	50	14	0,062	0,001	0,009	0,754	0,681	0,00%	95,00%
5	50	14	0,002	0,009	1,066	0,000	0,500	0,00%	97,84%
6	50	14	0,002	0,001	0,005	0,000	0,351	0,00%	95,00%
7	50	14	4,662	0,017	1,418	0,000	0,500	0,00%	95,00%
8	50	14	0,102	0,001	0,009	0,000	0,600	0,00%	95,00%
9	50	14	0,638	0,004	0,360	0,000	0,889	0,00%	96,47%
10	50	14	0,774	0,143	0,288	0,000	0,385	0,00%	95,00%
11	50	14	0,058	0,004	0,009	0,000	0,500	0,00%	95,00%
12	50	14	0,474	0,000	0,031	2,262	0,642	0,00%	97,84%
13	50	14	0,590	0,082	1,665	0,000	0,000	0,00%	95,00%
14	50	14	0,090	0,001	0,045	0,000	0,546	0,00%	97,84%
15	50	14	0,600	0,001	0,032	0,000	0,333	0,00%	95,00%
16	50	14	1,078	0,053	0,207	0,000	1,000	0,00%	95,00%
17	50	14	0,632	0,015	0,257	0,000	0,923	0,00%	96,47%
18	50	14	3,792	0,024	0,099	0,000	0,813	0,00%	95,00%
19	50	14	2,418	0,436	1,350	0,000	0,714	0,00%	95,00%
20	50	14	2,772	0,024	1,611	0,000	0,900	0,00%	95,00%
21	50	14	0,058	0,001	0,014	0,000	1,000	0,00%	95,00%
22	50	14	0,446	0,001	0,005	0,000	0,500	0,00%	95,00%
23	50	14	2,516	0,082	0,801	0,000	1,000	0,00%	95,00%
24	50	14	0,248	0,001	0,014	0,000	0,000	0,00%	95,00%
25	50	14	0,860	0,082	0,023	0,000	0,500	0,00%	95,00%
26	50	14	0,124	0,006	0,149	0,000	0,421	0,00%	95,00%
27	50	14	2,748	0,051	0,045	0,000	0,955	0,00%	95,00%
28	50	14	2,782	0,082	7,101	0,000	1,000	0,00%	95,00%
29	50	14	0,002	0,001	0,009	0,000	0,500	0,00%	95,00%
30	50	14	0,794	0,001	0,081	0,000	0,396	0,00%	95,00%
31	50	14	2,214	0,001	0,113	0,000	0,778	0,00%	96,47%
32	50	14	3,120	0,001	0,113	0,000	0,458	0,00%	96,47%
33	50	14	3,124	0,137	0,954	0,000	0,875	0,00%	95,00%
34	50	14	0,164	0,017	0,086	0,000	0,489	0,00%	97,84%
35	50	14	0,138	0,082	2,430	0,000	1,000	0,00%	95,00%
36	50	14	0,124	0,082	0,086	0,000	0,381	0,00%	96,47%
37	50	14	2,638	0,009	0,909	0,000	0,667	0,00%	95,00%
38	50	14	0,794	0,123	0,022	0,000	0,463	0,00%	96,47%
39	50	14	23,768	0,082	12,645	0,000	0,500	0,00%	90,10%
40	50	14	0,028	0,001	0,450	0,000	0,417	0,00%	95,00%
41	50	14	5,842	0,202	0,360	0,000	0,684	0,00%	90,10%
42	50	14	3,298	0,002	0,135	2,262	0,710	0,00%	97,84%
43	50	14	0,046	0,001	0,036	0,000	0,280	0,00%	95,00%
44	50	14	0,190	0,082	0,077	0,000	0,000	0,00%	95,00%
45	50	14	1,528	0,082	4,500	0,000	0,600	0,00%	95,00%
46	50	14	11,058	0,202	4,158	0,000	0,300	0,00%	95,00%
47	50	14	5,516	0,082	10,350	0,000	0,571	0,00%	90,10%
48	50	14	3,166	0,051	1,584	0,000	0,500	0,00%	95,00%
49	50	14	0,066	0,001	0,009	0,000	0,500	0,00%	95,00%
50	50	14	0,076	0,001	0,014	0,000	0,200	0,00%	95,00%
51	50	14	0,682	0,002	0,450	0,000	0,421	0,00%	96,47%
52	50	14	5,712	0,082	4,500	0,000	1,000	0,00%	90,10%
53	50	14	10,476	0,267	4,829	0,000	0,857	0,00%	90,10%
54	50	14	0,814	0,002	0,527	0,000	0,000	0,00%	95,00%
55	50	14	0,336	0,123	0,014	0,000	0,500	0,00%	95,00%
56	50	14	0,278	0,082	0,003	1,508	1,000	0,00%	95,00%
57	50	14	1,494	0,123	0,113	0,000	0,540	0,00%	95,00%
58	50	14	0,112	0,004	0,045	0,000	0,532	0,00%	96,47%

Part Nr.	Lead time sea (days)	Lead time air (days)	h (€/year)	c_t_sea (€/piece)	c_t_air (€/piece)	Demand rate/year	Fraction Class 1	Fill rate target (Class 1)	Fill rate target (Class 2)
59	50	14	33,712	1,079	7,389	0,000	0,731	0,00%	92,06%
60	50	14	0,238	0,030	0,023	0,000	0,500	0,00%	95,00%
61	50	14	2,376	0,082	2,250	0,000	1,000	0,00%	95,00%
62	50	14	3,350	0,013	0,207	0,000	0,444	0,00%	95,00%
63	50	14	0,150	0,001	0,005	0,000	0,857	0,00%	95,00%
64	50	14	0,056	0,001	0,067	0,000	0,577	0,00%	97,84%
65	50	14	3,454	0,002	0,468	0,000	1,000	0,00%	95,00%
66	50	14	6,288	0,141	0,900	0,000	0,750	0,00%	90,10%
67	50	14	0,700	0,001	0,040	0,000	0,464	0,00%	96,47%
68	50	14	0,280	0,082	0,225	0,000	0,700	0,00%	96,47%
69	50	14	9,350	0,009	0,450	0,000	0,500	0,00%	90,10%
70	50	14	8,764	0,436	7,200	0,000	0,633	0,00%	95,00%
71	50	14	1,558	0,001	0,270	0,000	0,688	0,00%	95,00%
72	50	14	0,038	0,001	0,023	0,000	0,909	0,00%	95,00%
73	50	14	10,720	2,521	10,800	0,000	0,478	0,00%	95,00%
74	50	14	151,952	0,257	2,250	18,853	0,458	0,00%	94,02%
75	50	14	15,112	0,139	0,450	0,000	0,714	0,00%	90,10%
76	50	14	2,242	0,006	0,464	0,000	0,583	0,00%	96,47%
77	50	14	0,310	0,001	0,027	1,508	0,868	0,00%	96,47%
78	50	14	0,258	0,123	0,495	24,886	0,000	0,00%	95,00%
79	50	14	5,850	0,082	3,668	0,000	0,667	0,00%	90,10%
80	50	14	8,994	0,082	4,230	0,754	0,703	0,00%	95,00%
81	50	14	30,294	0,082	0,450	0,000	1,000	0,00%	80,70%
82	50	14	6,806	0,082	0,752	0,000	0,667	0,00%	90,10%
83	50	14	0,426	0,082	0,315	0,000	0,500	0,00%	95,00%
84	50	14	13,992	0,082	5,400	0,000	0,750	0,00%	90,10%
85	50	14	1,116	0,082	0,095	0,000	1,000	0,00%	95,00%
86	50	14	0,494	0,001	0,450	0,000	0,187	0,00%	97,84%
87	50	14	0,242	0,001	0,450	0,000	0,667	0,00%	95,00%
88	50	14	0,566	0,123	0,450	0,000	0,615	0,00%	95,00%
89	50	14	5,124	0,082	2,250	1,508	0,627	0,00%	95,98%
90	50	14	9,048	0,873	6,750	0,000	0,786	0,00%	95,00%
91	50	14	1,288	0,006	0,185	0,000	0,594	0,00%	96,47%
92	50	14	21,862	0,082	1,800	0,000	0,625	0,00%	90,10%
93	50	14	19,820	0,082	1,467	0,000	0,833	0,00%	90,10%
94	50	14	2,644	0,082	4,172	0,000	0,517	0,00%	95,00%
95	50	14	1,044	0,141	0,720	0,000	0,500	0,00%	95,00%
96	50	14	2,400	0,033	0,113	0,000	0,000	0,00%	95,00%
97	50	14	39,258	0,082	2,880	3,017	0,701	0,00%	92,06%
98	50	14	3,486	0,082	0,360	0,000	0,500	0,00%	95,00%
99	50	14	13,958	0,082	9,000	0,754	0,712	0,00%	95,00%
100	50	14	29,288	0,082	29,250	0,000	0,875	0,00%	90,10%
101	50	14	30,842	0,082	23,850	2,262	0,933	0,00%	92,06%
102	50	14	4,064	0,082	0,509	0,000	0,780	0,00%	95,00%
103	50	14	25,530	0,082	11,700	0,000	0,609	0,00%	95,98%
104	50	14	4,200	0,082	0,833	25,640	0,469	0,00%	95,00%
105	50	14	85,266	0,082	13,500	0,000	1,000	0,00%	80,70%
106	50	14	65,124	0,082	38,250	0,754	0,818	0,00%	80,70%
107	50	14	96,866	0,082	2,399	0,000	0,500	0,00%	94,02%
108	50	14	96,738	0,082	2,250	0,000	0,500	0,00%	80,70%
109	50	14	96,746	0,082	2,250	0,000	0,500	0,00%	80,70%
110	50	14	31,526	22,797	90,000	0,000	0,000	0,00%	80,70%
111	50	14	12,000	1,065	5,400	0,000	0,007	0,00%	95,00%
112	50	14	0,310	0,082	0,003	0,000	1,000	0,00%	95,00%

Table 11.8: Data set used for RSHQ 3

Appendix H Model output

Part Nr. (ID)	S	c	Fill rate (Class 1)	Fill rate (Class 2)	Total costs/year
1	10	1	97,29%	88,29%	8,604709
2	49	0	97,24%	97,24%	1,911458
3	28	0	99,29%	99,29%	1,550505
4	77	0	98,27%	98,27%	3,003558
5	1443	0	99,95%	99,95%	1,305315
6	70	0	99,38%	99,38%	0,131947
7	1	0	98,16%	98,16%	4,576111
8	4	1	98,90%	83,63%	0,272389
9	12	0	99,81%	99,81%	7,047299
10	28	1	97,34%	83,51%	7,253517
11	70	0	97,78%	97,78%	2,157372
12	630	14	99,90%	94,92%	72,91373
13	6	0	98,99%	98,99%	3,024536
14	882	16	99,91%	86,44%	17,38758
15	70	4	97,07%	85,47%	11,89098
16	49	0	97,13%	97,13%	13,44268
17	84	4	98,52%	92,43%	15,80343
18	4	0	98,92%	98,92%	11,97919
19	26	0	97,43%	97,43%	29,36774
20	12	1	97,41%	92,43%	14,95164
21	16	0	97,15%	97,15%	0,518565
22	20	0	99,38%	99,38%	8,405054
23	8	1	97,88%	92,71%	11,14989
24	10	0	98,98%	98,98%	2,29414
25	2	0	99,84%	99,84%	1,670275
26	52	0	98,25%	98,25%	3,190589
27	23	1	97,29%	93,73%	21,33452
28	24	1	97,12%	92,81%	37,01416
29	20	0	99,95%	99,95%	0,03938
30	8	1	98,97%	88,87%	4,559213
31	72	3	98,56%	96,00%	37,37671
32	72	4	98,52%	94,68%	52,42745
33	8	0	97,44%	97,44%	14,19155
34	42	2	99,91%	96,59%	5,508578
35	5	0	97,43%	97,43%	0,465367
36	144	0	98,50%	98,50%	5,137018
37	8	0	98,66%	98,66%	13,02635
38	68	6	98,54%	86,84%	11,80264
39	27	2	92,19%	83,61%	167,1334
40	12	0	97,49%	97,49%	0,16281
41	16	0	93,57%	93,57%	33,12754
42	580	13	99,90%	95,21%	483,4242
43	46	3	97,14%	83,31%	0,68434
44	16	0	99,20%	99,20%	2,454558
45	65	1	97,05%	96,00%	21,96141
46	6	0	98,52%	98,52%	55,22031
47	18	1	93,05%	86,59%	30,8142
48	6	0	97,23%	97,23%	11,88931
49	9	0	99,03%	99,03%	0,508722
50	14	0	98,65%	98,65%	0,688899
51	51	5	98,58%	90,18%	9,265446
52	5	0	95,52%	95,52%	17,75844
53	2	0	94,74%	94,74%	17,19226
54	22	0	97,57%	97,57%	9,035761
55	6	0	99,17%	99,17%	1,88032
56	5	1	100,00%	83,13%	0,822381
57	60	5	97,10%	83,80%	18,68589

Part Nr. (ID)	S	c	Fill rate (Class 1)	Fill rate (Class 2)	Total costs/year
58	408	7	98,60%	89,66%	8,609488
59	188	5	94,06%	82,13%	946,518
60	6	0	99,67%	99,67%	1,290431
61	1	0	100,00%	100,00%	2,376
62	4	0	99,19%	99,19%	12,5096
63	141	0	99,35%	99,35%	18,53261
64	360	4	99,90%	95,42%	12,00484
65	8	0	98,73%	98,73%	17,16139
66	29	1	92,13%	87,33%	44,61666
67	238	7	98,55%	91,31%	29,68604
68	15	0	99,67%	99,67%	3,383062
69	5	0	96,51%	96,51%	30,23757
70	5	0	98,89%	98,89%	32,32874
71	9	1	97,09%	91,94%	7,177091
72	24	0	98,94%	98,94%	0,7212
73	5	0	99,01%	99,01%	39,93854
74	152	5	96,15%	84,24%	4155,087
75	11	0	94,05%	94,05%	70,86806
76	82	5	98,53%	92,02%	38,32422
77	176	0	98,53%	98,53%	11,9068
78	6	1	99,60%	86,65%	0,878013
79	16	0	94,03%	94,03%	45,68622
80	172	1	97,04%	96,05%	298,0929
81	80	0	82,47%	82,46%	276,5206
82	10	0	94,62%	94,62%	30,92121
83	1	0	98,16%	98,16%	0,418152
84	79	0	92,08%	92,07%	174,2968
85	4	0	97,84%	97,84%	3,307672
86	600	16	99,91%	88,87%	70,01292
87	30	0	97,52%	97,51%	3,793788
88	14	0	97,15%	97,15%	3,526166
89	448	4	98,00%	94,50%	413,162
90	77	3	97,02%	92,64%	137,4721
91	150	7	98,59%	87,39%	42,34546
92	69	1	92,12%	89,88%	252,3757
93	74	1	92,17%	90,03%	237,8105
94	58	1	97,10%	95,79%	35,50773
95	7	1	97,14%	92,10%	4,246616
96	2	0	98,66%	98,66%	4,38539
97	7	0	96,86%	96,86%	159,355
98	12	0	97,37%	97,37%	20,12262
99	408	6	97,10%	86,99%	955,9137
100	37	1	92,67%	88,95%	244,114
101	115	3	94,00%	89,31%	500,324
102	114	6	97,24%	86,09%	70,92996
103	1232	6	98,14%	90,41%	5428,41
104	114	2	99,01%	82,84%	80,10097
105	66	0	84,75%	84,74%	755,4574
106	79	3	82,66%	71,19%	579,7512
107	48	0	97,24%	97,24%	2611,598
108	6	0	95,89%	95,89%	489,4195
109	6	0	96,54%	96,54%	497,538
110	7	0	84,81%	84,81%	87,28467
111	10	0	97,59%	97,59%	62,98931
112	3	0	97,32%	97,31%	0,734185

Table 11.9: Model output for CSC

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
1	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
2	24	1	Air	99,96%	98,91%	1,41	0,43	0,34	2,17
3	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
4	15	2	Air	99,99%	97,90%	0,82	0,43	0,17	1,42
5	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
6	126	3	Sea	100,00%	96,71%	0,22	0,19	0,01	0,42
7	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
8	4	2	Air	100,00%	97,56%	0,38	0,06	0,00	0,45
9	8	1	Sea	99,92%	99,08%	4,56	0,57	0,24	5,37
10	20	1	Sea	99,61%	95,51%	11,43	9,67	2,96	24,06
11	24	1	Air	99,94%	98,22%	1,30	0,39	0,47	2,16
12	32	1	Air	99,89%	98,55%	13,27	4,49	2,81	20,57
13	4	0	Sea	99,58%	99,58%	2,25	0,24	0,00	2,48
14	180	3	Sea	99,99%	98,00%	10,87	5,97	1,35	18,19
15	6	1	Air	99,86%	95,87%	3,22	0,74	0,26	4,21
16	6	0	Air	99,91%	99,91%	6,07	1,96	0,33	8,36
17	20	1	Sea	99,86%	98,60%	11,07	1,86	1,30	14,23
18	6	1	Air	99,75%	96,55%	20,57	3,38	1,22	25,16
19	6	1	Sea	99,68%	95,57%	12,91	3,89	0,60	17,41
20	6	0	Sea	98,79%	98,79%	13,96	2,86	4,09	20,91
21	6	0	Air	99,97%	99,97%	0,33	0,09	0,08	0,50
22	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
23	2	0	Air	99,36%	99,36%	4,73	2,10	0,73	7,56
24	8	0	Air	96,44%	96,44%	1,91	0,15	0,00	2,07
25	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
26	20	1	Sea	99,98%	99,41%	2,26	0,31	0,06	2,63
27	5	1	Air	99,86%	98,95%	11,43	3,05	1,15	15,63
28	4	0	Sea	99,08%	99,08%	10,32	0,99	1,04	12,35
29	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
30	10	1	Air	99,88%	98,21%	6,38	4,79	0,99	12,16
31	9	0	Air	99,56%	99,56%	17,74	4,47	3,50	25,71
32	9	0	Air	99,67%	99,67%	25,32	4,80	1,39	31,50
33	6	0	Air	99,56%	99,56%	17,83	6,65	1,16	25,64
34	133	1	Sea	99,94%	99,42%	16,86	9,09	3,33	29,28
35	3	0	Sea	99,91%	99,91%	0,39	0,15	0,07	0,61
36	16	1	Air	99,98%	99,30%	1,79	2,90	0,15	4,84
37	2	0	Sea	96,87%	96,87%	4,55	0,75	2,36	7,65
38	32	2	Air	99,98%	98,40%	19,11	9,96	0,73	29,80
39	2	0	Sea	94,15%	94,15%	38,32	9,46	4,41	52,19
40	16	2	Sea	100,00%	96,66%	0,42	0,04	0,01	0,47
41	6	1	Air	99,64%	95,07%	30,96	9,24	1,77	41,97
42	28	1	Air	99,82%	98,05%	79,37	23,86	5,02	108,24
43	18	3	Sea	100,00%	96,12%	0,60	0,28	0,01	0,89
44	2	0	Air	98,53%	98,53%	0,35	0,32	0,00	0,67
45	3	0	Sea	98,83%	98,83%	3,86	1,03	1,32	6,22
46	4	0	Sea	98,54%	98,54%	33,90	11,84	1,65	47,40
47	3	0	Sea	96,81%	96,81%	12,71	4,26	4,81	21,78
48	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
49	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
50	3	1	Air	99,98%	98,50%	0,21	0,06	0,01	0,29
51	10	2	Sea	99,94%	96,85%	4,36	2,52	0,37	7,25
52	1	0	Sea	91,27%	91,27%	5,21	0,56	3,29	9,06
53	3	0	Sea	97,46%	97,46%	24,68	8,13	5,74	38,54
54	6	0	Sea	96,62%	96,62%	4,19	0,70	0,00	4,90
55	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
56	6	1	Air	99,94%	98,79%	1,58	0,11	0,17	1,85
57	10	1	Air	99,84%	98,27%	12,03	7,14	1,63	20,81
58	80	3	Sea	99,99%	96,60%	6,27	3,47	0,68	10,42

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
59	8	0	Sea	96,18%	96,18%	182,08	108,17	27,37	317,63
60	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
61	4	0	Sea	99,14%	99,14%	8,84	0,85	0,98	10,67
62	4	0	Air	98,84%	98,84%	12,32	2,48	1,75	16,55
63	10	0	Air	99,87%	99,87%	1,46	0,06	0,28	1,81
64	108	3	Sea	100,00%	98,16%	4,67	1,64	0,25	6,57
65	2	0	Air	99,75%	99,75%	6,66	0,96	0,19	7,80
66	3	1	Air	98,92%	90,44%	15,65	11,30	3,66	30,60
67	20	1	Air	99,94%	99,11%	11,77	4,79	0,88	17,44
68	6	2	Sea	99,98%	98,45%	1,42	0,88	0,05	2,35
69	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
70	8	1	Sea	99,57%	97,58%	45,50	34,44	3,07	83,01
71	4	1	Air	99,79%	97,73%	5,30	4,18	0,86	10,35
72	15	3	Sea	100,00%	95,24%	0,53	0,05	0,01	0,59
73	15	0	Sea	98,60%	98,60%	114,81	132,85	11,63	259,29
74	126	0	Air	95,69%	95,69%	9092,36	13155,65	1388,27	23636,27
75	2	0	Air	97,39%	97,39%	26,43	6,13	4,93	37,48
76	15	2	Sea	99,88%	97,74%	18,33	15,64	1,85	35,82
77	16	1	Air	99,96%	99,47%	4,53	1,20	0,46	6,19
78	2	0	Sea	98,37%	98,37%	0,47	0,23	0,00	0,70
79	2	0	Sea	96,81%	96,81%	10,06	1,82	2,41	14,29
80	12	0	Sea	97,01%	97,01%	75,62	34,55	29,32	139,49
81	2	0	Air	96,30%	96,30%	51,30	11,58	9,78	72,65
82	2	0	Air	97,86%	97,86%	12,08	4,88	3,22	20,19
83	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
84	9	0	Sea	97,59%	97,59%	99,60	27,55	13,61	140,75
85	2	0	Air	99,75%	99,75%	2,15	0,22	0,19	2,56
86	80	1	Sea	99,97%	99,33%	28,88	10,85	0,48	40,21
87	28	1	Sea	99,83%	98,01%	5,82	1,00	1,79	8,60
88	8	1	Sea	99,79%	97,56%	3,84	1,89	0,62	6,35
89	42	1	Sea	99,44%	96,36%	150,53	72,96	17,86	241,34
90	12	1	Sea	98,99%	95,04%	72,82	63,18	12,57	148,56
91	24	1	Air	99,73%	96,98%	25,77	19,86	6,31	51,95
92	2	0	Air	96,17%	96,17%	36,98	17,34	7,22	61,54
93	3	1	Air	99,07%	91,91%	50,23	22,41	3,49	76,13
94	8	1	Sea	99,68%	97,83%	13,91	9,03	1,79	24,73
95	2	0	Sea	98,41%	98,41%	1,89	0,41	0,60	2,90
96	1	0	Air	96,41%	96,41%	2,31	0,17	0,00	2,48
97	10	1	Air	98,72%	92,74%	270,84	309,00	29,35	609,19
98	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
99	36	0	Sea	97,47%	97,47%	308,57	202,81	99,19	610,56
100	6	0	Sea	91,52%	91,52%	133,11	43,53	44,76	221,41
101	4	0	Sea	95,57%	95,57%	80,69	43,57	23,37	147,63
102	18	1	Air	99,65%	95,55%	65,07	27,20	5,16	97,43
103	72	0	Sea	98,37%	98,37%	1204,24	649,64	95,90	1949,77
104	88	2	Sea	99,81%	96,31%	155,05	247,81	18,39	421,25
105	2	0	Sea	90,96%	90,96%	155,11	15,53	6,82	177,46
106	3	0	Sea	91,26%	91,26%	125,90	70,10	29,67	225,68
107	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
108	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
109	0	0	Sea	100,00%	100,00%	0,00	0,00	0,00	0,00
110	1	0	Sea	81,05%	81,05%	25,55	40,36	0,00	65,91
111	294	0	Air	96,31%	96,31%	3397,64	1376,19	2,79	4776,61
112	22	0	Air	99,94%	99,94%	6,70	0,15	0,27	7,11

Table 11.10: Model output for RSHQ 1

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
1	15	1	Sea	99,92%	98,90%	16,86497412	5,848036771	0,396759309	23,1097702
2	0	0	Sea	100,00%	100,00%	0	0	0	0
3	0	0	Sea	100,00%	100,00%	0	0	0	0
4	2	1	Air	99,96%	96,38%	0,121726783	0,00905834	0,011487971	0,142273093
5	0	0	Sea	100,00%	100,00%	0	0	0	0
6	0	0	Sea	100,00%	100,00%	0	0	0	0
7	0	0	Sea	100,00%	100,00%	0	0	0	0
8	0	0	Sea	100,00%	100,00%	0	0	0	0
9	0	0	Sea	100,00%	100,00%	0	0	0	0
10	0	0	Sea	100,00%	100,00%	0	0	0	0
11	0	0	Sea	100,00%	100,00%	0	0	0	0
12	18	1	Air	99,98%	99,16%	8,147833853	0,906701501	0,124256938	9,178792293
13	0	0	Sea	100,00%	100,00%	0	0	0	0
14	52	1	Sea	99,98%	99,60%	4,313987189	0,386825005	0,134511058	4,835323251
15	1	0	Air	95,86%	95,86%	0,575148564	0,048278629	0,520590057	1,14401725
16	2	0	Air	99,93%	99,93%	2,116107793	0,19589444	0,024912754	2,336914987
17	0	0	Sea	100,00%	100,00%	0	0	0	0
18	2	0	Air	96,50%	96,50%	7,318379343	0,410689746	2,146006491	9,87507558
19	2	0	Sea	98,29%	98,29%	4,352826826	0,809969786	0,921515215	6,084311828
20	0	0	Sea	100,00%	100,00%	0	0	0	0
21	0	0	Sea	100,00%	100,00%	0	0	0	0
22	0	0	Sea	100,00%	100,00%	0	0	0	0
23	2	0	Sea	98,23%	98,23%	4,516931351	0,576408542	1,331226717	6,42456661
24	0	0	Sea	100,00%	100,00%	0	0	0	0
25	0	0	Sea	100,00%	100,00%	0	0	0	0
26	0	0	Sea	100,00%	100,00%	0	0	0	0
27	2	0	Air	99,73%	99,73%	5,286642516	0,277054062	0,194803823	5,7585004
28	0	0	Sea	100,00%	100,00%	0	0	0	0
29	0	0	Sea	100,00%	100,00%	0	0	0	0
30	4	0	Air	99,74%	99,74%	3,058305417	0,361782074	0,1551559	3,57524339
31	2	0	Air	99,75%	99,75%	4,26547085	0,331875271	0,148280698	4,745626818
32	2	0	Sea	99,53%	99,53%	5,925756667	0,314710641	0,081174207	6,321641515
33	1	0	Air	96,44%	96,44%	3,01272814	0,808291888	1,175163597	4,996183625
34	32	1	Sea	99,95%	98,99%	4,67350394	0,802093527	0,325803516	5,801400982
35	0	0	Sea	100,00%	100,00%	0	0	0	0
36	3	1	Sea	99,96%	98,23%	0,347172054	0,087259834	0,012391622	0,446823511
37	0	0	Sea	100,00%	100,00%	0	0	0	0
38	4	1	Air	99,97%	99,37%	2,884347955	0,461311996	0,044003984	3,389663934
39	0	0	Sea	100,00%	100,00%	0	0	0	0
40	0	0	Sea	100,00%	100,00%	0	0	0	0
41	0	0	Sea	100,00%	100,00%	0	0	0	0
42	12	0	Air	99,39%	99,39%	37,2760707	4,225843289	3,124144029	44,62605801
43	3	1	Sea	99,96%	98,11%	0,128456523	0,010584076	0,007444078	0,146484677
44	0	0	Sea	100,00%	100,00%	0	0	0	0
45	2	0	Sea	99,53%	99,53%	2,901736946	0,18539608	0,10633862	3,193471646
46	2	0	Sea	98,28%	98,28%	19,91987525	2,348523615	0,390153204	22,65855207
47	4	0	Sea	98,07%	98,07%	19,72045489	2,467051407	1,664249438	23,85175574
48	1	0	Air	96,40%	96,40%	3,05189711	1,287123825	0,679435602	5,018456537
49	0	0	Sea	100,00%	100,00%	0	0	0	0
50	0	0	Sea	100,00%	100,00%	0	0	0	0
51	4	0	Sea	98,25%	98,25%	2,45431699	0,276782138	1,110122053	3,841221181
52	0	0	Sea	100,00%	100,00%	0	0	0	0
53	1	0	Sea	90,82%	90,82%	9,514602547	1,054859719	2,966047578	13,53550985
54	0	0	Sea	100,00%	100,00%	0	0	0	0
55	0	0	Sea	100,00%	100,00%	0	0	0	0
56	0	0	Sea	100,00%	100,00%	0	0	0	0
57	3	1	Air	99,94%	98,33%	4,191534983	0,714536558	0,056817457	4,962888998
58	18	1	Sea	99,92%	97,90%	1,868411395	0,167873926	0,202360663	2,238645984

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
59	0	0	Sea	100,00%	100,00%	0	0	0	0
60	0	0	Sea	100,00%	100,00%	0	0	0	0
61	4	0	Air	99,75%	99,75%	12,9160203	1,107716493	0,165384138	14,18912094
62	0	0	Sea	100,00%	100,00%	0	0	0	0
63	30	1	Sea	99,99%	99,53%	1,623622335	0,061580908	0,019484084	1,704687328
64	0	0	Sea	100,00%	100,00%	0	0	0	0
65	0	0	Sea	100,00%	100,00%	0	0	0	0
66	4	0	Air	99,93%	99,93%	2,746922502	0,114142434	0,024412837	2,885477774
67	4	0	Air	99,86%	99,86%	1,089658968	0,538881083	0,110934403	1,739474455
68	1	0	Air	96,45%	96,45%	9,018080476	0,665255831	0,669244049	10,35258036
69	2	0	Sea	96,52%	96,52%	14,96251218	3,050806986	2,493675929	20,5069951
70	0	0	Sea	100,00%	100,00%	0	0	0	0
71	0	0	Sea	100,00%	100,00%	0	0	0	0
72	3	0	Sea	96,86%	96,86%	24,78523875	13,97611423	3,968611425	42,72996441
73	20	0	Air	94,91%	94,91%	1973,731474	1395,098152	174,9573488	3543,786975
74	9	0	Air	93,83%	93,83%	127,617372	13,58111358	26,58516059	167,7836462
75	2	0	Air	99,03%	99,03%	4,15317768	1,721056824	0,855086601	6,729321105
76	6	0	Air	99,75%	99,75%	1,792599775	0,189308532	0,483545211	2,465453518
77	0	0	Sea	100,00%	100,00%	0	0	0	0
78	1	0	Sea	90,62%	90,62%	5,301137301	0,578130948	2,358484508	8,237752757
79	4	0	Sea	98,91%	98,91%	33,15301305	2,915934755	0,864030541	36,93297835
80	1	0	Air	91,66%	91,66%	27,76708437	3,149020597	6,290448671	37,20655364
81	1	0	Air	96,31%	96,31%	6,554524058	0,804246554	0,928793065	8,287563677
82	0	0	Sea	100,00%	100,00%	0	0	0	0
83	0	0	Sea	100,00%	100,00%	0	0	0	0
84	0	0	Sea	100,00%	100,00%	0	0	0	0
85	21	0	Sea	99,63%	99,63%	9,317571792	1,066255971	0,553554551	10,93738231
86	0	0	Sea	100,00%	100,00%	0	0	0	0
87	0	0	Sea	100,00%	100,00%	0	0	0	0
88	15	0	Sea	99,50%	99,50%	68,08996788	9,299142899	1,989721111	79,37883189
89	2	0	Sea	98,30%	98,30%	16,28964129	2,460420615	1,008529104	19,75859101
90	4	0	Air	99,22%	99,22%	4,812908713	1,308528623	1,226135733	7,347573069
91	2	0	Air	94,32%	94,32%	41,24138246	6,410417264	4,01428692	51,66608664
92	0	0	Sea	100,00%	100,00%	0	0	0	0
93	2	0	Sea	99,53%	99,53%	5,021999619	0,297145891	0,091261958	5,410407467
94	0	0	Sea	100,00%	100,00%	0	0	0	0
95	0	0	Sea	100,00%	100,00%	0	0	0	0
96	2	0	Air	98,61%	98,61%	71,49151152	17,77800532	1,840057175	91,10957401
97	0	0	Sea	100,00%	100,00%	0	0	0	0
98	10	0	Sea	95,50%	95,50%	115,9818313	24,11190263	20,56080252	160,6545364
99	1	0	Sea	90,46%	90,46%	26,49302899	2,823585071	3,148568091	32,46518215
100	0	0	Sea	100,00%	100,00%	0	0	0	0
101	2	0	Air	99,70%	99,70%	7,8034056	1,089766092	0,175101944	9,068273636
102	22	0	Sea	96,46%	96,46%	478,7195544	83,91795072	26,04983661	588,6873417
103	36	1	Sea	99,38%	95,14%	102,1238261	52,68732798	12,66975835	167,4809124
104	1	0	Sea	82,56%	82,56%	70,39755085	14,92000281	13,15034919	98,46790285
105	2	0	Sea	89,91%	89,91%	117,1039804	13,20130612	6,226646846	136,5319333
106	0	0	Sea	100,00%	100,00%	0	0	0	0
107	0	0	Sea	100,00%	100,00%	0	0	0	0
108	0	0	Sea	100,00%	100,00%	0	0	0	0
109	0	0	Sea	100,00%	100,00%	0	0	0	0
110	25	0	Air	96,45%	96,45%	289,3419617	112,4422497	0,218887447	402,0030988
111	0	0	Sea	100,00%	100,00%	0	0	0	0
112	0	0	Sea	100,00%	100,00%	0	0	0	0

Table 11.11: Model output for RSHQ 2

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
1	1	0	Air	96,31%	96,31%	1,304100944	0,982597705	0,694760398	2,981459048
2	0	0	Sea	100,00%	100,00%	0	0	0	0
3	0	0	Sea	100,00%	100,00%	0	0	0	0
4	2	1	Air	99,96%	96,38%	0,121726783	0,00905834	0,011487971	0,142273093
5	0	0	Sea	100,00%	100,00%	0	0	0	0
6	0	0	Sea	100,00%	100,00%	0	0	0	0
7	0	0	Sea	100,00%	100,00%	0	0	0	0
8	0	0	Sea	100,00%	100,00%	0	0	0	0
9	0	0	Sea	100,00%	100,00%	0	0	0	0
10	0	0	Sea	100,00%	100,00%	0	0	0	0
11	0	0	Sea	100,00%	100,00%	0	0	0	0
12	10	0	Air	99,98%	99,98%	4,687560519	0,123693986	0,017445902	4,828700407
13	0	0	Sea	100,00%	100,00%	0	0	0	0
14	0	0	Sea	100,00%	100,00%	0	0	0	0
15	0	0	Sea	100,00%	100,00%	0	0	0	0
16	0	0	Sea	100,00%	100,00%	0	0	0	0
17	0	0	Sea	100,00%	100,00%	0	0	0	0
18	0	0	Sea	100,00%	100,00%	0	0	0	0
19	0	0	Sea	100,00%	100,00%	0	0	0	0
20	0	0	Sea	100,00%	100,00%	0	0	0	0
21	0	0	Sea	100,00%	100,00%	0	0	0	0
22	0	0	Sea	100,00%	100,00%	0	0	0	0
23	0	0	Sea	100,00%	100,00%	0	0	0	0
24	0	0	Sea	100,00%	100,00%	0	0	0	0
25	0	0	Sea	100,00%	100,00%	0	0	0	0
26	0	0	Sea	100,00%	100,00%	0	0	0	0
27	0	0	Sea	100,00%	100,00%	0	0	0	0
28	0	0	Sea	100,00%	100,00%	0	0	0	0
29	0	0	Sea	100,00%	100,00%	0	0	0	0
30	0	0	Sea	100,00%	100,00%	0	0	0	0
31	0	0	Sea	100,00%	100,00%	0	0	0	0
32	0	0	Sea	100,00%	100,00%	0	0	0	0
33	0	0	Sea	100,00%	100,00%	0	0	0	0
34	0	0	Sea	100,00%	100,00%	0	0	0	0
35	0	0	Sea	100,00%	100,00%	0	0	0	0
36	0	0	Sea	100,00%	100,00%	0	0	0	0
37	0	0	Sea	100,00%	100,00%	0	0	0	0
38	0	0	Sea	100,00%	100,00%	0	0	0	0
39	0	0	Sea	100,00%	100,00%	0	0	0	0
40	0	0	Sea	100,00%	100,00%	0	0	0	0
41	0	0	Sea	100,00%	100,00%	0	0	0	0
42	10	0	Sea	99,79%	99,79%	31,88099108	1,103651221	0,168571446	33,15321374
43	0	0	Sea	100,00%	100,00%	0	0	0	0
44	0	0	Sea	100,00%	100,00%	0	0	0	0
45	0	0	Sea	100,00%	100,00%	0	0	0	0
46	0	0	Sea	100,00%	100,00%	0	0	0	0
47	0	0	Sea	100,00%	100,00%	0	0	0	0
48	0	0	Sea	100,00%	100,00%	0	0	0	0
49	0	0	Sea	100,00%	100,00%	0	0	0	0
50	0	0	Sea	100,00%	100,00%	0	0	0	0
51	0	0	Sea	100,00%	100,00%	0	0	0	0
52	0	0	Sea	100,00%	100,00%	0	0	0	0
53	0	0	Sea	100,00%	100,00%	0	0	0	0
54	0	0	Sea	100,00%	100,00%	0	0	0	0
55	0	0	Sea	100,00%	100,00%	0	0	0	0
56	3	1	Air	99,99%	99,59%	0,807926906	0,030144899	0,009444247	0,847516051
57	0	0	Sea	100,00%	100,00%	0	0	0	0
58	0	0	Sea	100,00%	100,00%	0	0	0	0

Part Nr.	S	c	Sea/ Air	Fill rate (Class 1)	Fill rate (Class 2)	Holding costs/year	Transportation costs/year	Emergency costs/year	Total costs/year
59	0	0	Sea	100,00%	100,00%	0	0	0	0
60	0	0	Sea	100,00%	100,00%	0	0	0	0
61	0	0	Sea	100,00%	100,00%	0	0	0	0
62	0	0	Sea	100,00%	100,00%	0	0	0	0
63	0	0	Sea	100,00%	100,00%	0	0	0	0
64	0	0	Sea	100,00%	100,00%	0	0	0	0
65	0	0	Sea	100,00%	100,00%	0	0	0	0
66	0	0	Sea	100,00%	100,00%	0	0	0	0
67	0	0	Sea	100,00%	100,00%	0	0	0	0
68	0	0	Sea	100,00%	100,00%	0	0	0	0
69	0	0	Sea	100,00%	100,00%	0	0	0	0
70	0	0	Sea	100,00%	100,00%	0	0	0	0
71	0	0	Sea	100,00%	100,00%	0	0	0	0
72	0	0	Sea	100,00%	100,00%	0	0	0	0
73	6	0	Air	96,42%	96,42%	776,9948039	176,4417708	15,45251808	968,8890928
74	0	0	Sea	100,00%	100,00%	0	0	0	0
75	0	0	Sea	100,00%	100,00%	0	0	0	0
76	4	0	Air	99,94%	99,94%	1,217495783	0,06320483	0,041717528	1,322418141
77	36	0	Sea	98,14%	98,14%	8,333919959	4,00893095	0	12,34285091
78	0	0	Sea	100,00%	100,00%	0	0	0	0
79	2	0	Air	97,96%	97,96%	17,62126346	3,51101463	0,540203835	21,67248193
80	0	0	Sea	100,00%	100,00%	0	0	0	0
81	0	0	Sea	100,00%	100,00%	0	0	0	0
82	0	0	Sea	100,00%	100,00%	0	0	0	0
83	0	0	Sea	100,00%	100,00%	0	0	0	0
84	0	0	Sea	100,00%	100,00%	0	0	0	0
85	0	0	Sea	100,00%	100,00%	0	0	0	0
86	0	0	Sea	100,00%	100,00%	0	0	0	0
87	0	0	Sea	100,00%	100,00%	0	0	0	0
88	4	0	Air	98,18%	98,18%	20,12253064	3,728301445	0,861399069	24,71223115
89	0	0	Sea	100,00%	100,00%	0	0	0	0
90	0	0	Sea	100,00%	100,00%	0	0	0	0
91	0	0	Sea	100,00%	100,00%	0	0	0	0
92	0	0	Sea	100,00%	100,00%	0	0	0	0
93	0	0	Sea	100,00%	100,00%	0	0	0	0
94	0	0	Sea	100,00%	100,00%	0	0	0	0
95	0	0	Sea	100,00%	100,00%	0	0	0	0
96	2	0	Sea	93,38%	93,38%	62,07601432	16,67643363	7,001659395	85,75410734
97	0	0	Sea	100,00%	100,00%	0	0	0	0
98	4	0	Sea	97,23%	97,23%	54,28475596	1,60801002	0,744335555	56,63710154
99	0	0	Sea	100,00%	100,00%	0	0	0	0
100	2	0	Sea	95,87%	95,87%	51,65846315	10,20433277	4,363195681	66,2259916
101	0	0	Sea	100,00%	100,00%	0	0	0	0
102	0	0	Sea	100,00%	100,00%	0	0	0	0
103	12	1	Sea	99,46%	95,64%	34,53682751	17,96549051	3,242546884	55,7448649
104	0	0	Sea	100,00%	100,00%	0	0	0	0
105	1	0	Sea	89,06%	89,06%	58,00175495	7,178687888	3,373982899	68,55442574
106	0	0	Sea	100,00%	100,00%	0	0	0	0
107	0	0	Sea	100,00%	100,00%	0	0	0	0
108	0	0	Sea	100,00%	100,00%	0	0	0	0
109	0	0	Sea	100,00%	100,00%	0	0	0	0
110	0	0	Sea	100,00%	100,00%	0	0	0	0
111	0	0	Sea	100,00%	100,00%	0	0	0	0
112	0	0	Sea	100,00%	100,00%	0	0	0	0

Table 11.12: Model output for RSHQ 3

Appendix I Verification through manual calculation

Enders et al. (2014)

For verification of the implemented model of Enders et al. (2014) the following test item and parameter settings were used:

Part Nr. (ID)	1001
h (RSHQ)	1
c_t (sea)	1
c_t (air)	5
Demand rate/year	10
Fraction Class 1	0,5
Fill rate target (Class 1)	0,0%
Fill rate target (Class 2)	90,0%

Table 11.13: Test item with input variable values for RSHQ

S (CSC)	1001
c (CSC)	0
Review period (days)	7
Lead time (Sea) (days)	14
Lead time (Air) (days)	7
Transp. Cost/piece (Emergency shipment)	10

Table 11.14: Parameter settings used for test RSHQ

This led the model to determine the order-up-to level to be $S = 3$ and a critical level $c = 1$. The manual calculation with these parameter settings leads to the following sub matrices:

$$B_0 = \begin{pmatrix} -67{,}5714 & 62{,}5714 & 0 & 0 \\ 5 & -51{,}7143 & 41{,}7143 & 0 \\ 0 & 10 & -30{,}8571 & 20{,}8571 \\ 0 & 0 & 10 & -10 \end{pmatrix},$$

$$B_1 = \begin{pmatrix} 5 & 0 \\ 0 & 5 \\ 0 & 0 \\ 0 & 0 \end{pmatrix},$$

$$B_{-1} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 62{,}5714 & 0 & 0 \end{pmatrix},$$

$$A_0(1) = \begin{pmatrix} -88{,}4286 & 83{,}4286 \\ 5 & -72{,}5714 \end{pmatrix},$$

$$A_0(2) = \begin{pmatrix} -109{,}286 & 104{,}2857 \\ 5 & -93{,}4286 \end{pmatrix},$$

$$A_0(3) = \begin{pmatrix} -130{,}143 & 125{,}1429 \\ 5 & -114{,}286 \end{pmatrix},$$

$$A_0(4) = \begin{pmatrix} -151 & 146 \\ 5 & -135{,}143 \end{pmatrix},$$

$$A_1 = \begin{pmatrix} 5 & 0 \\ 0 & 5 \end{pmatrix}.$$

By applying the methods of Enders et al. (2014) that are described in section 6.2, the following expected fill rates and yearly costs are obtained and compared with the output of the tool:

Output variable	Manual calculation	Model output
Fill rate (Class 1)	99,40%	99,40%
Fill rate (Class 2)	91,63%	91,63%
Holding costs/year	€ 2,53	€ 2,53
Transportation costs/year	€ 10,44	€ 10,44
Emergency costs/year	€ 0,30	€ 0,30
Total costs/year	€ 13,27	€ 13,27

Table 11.15: Output values at RSHQ for test part

Deshpande et al. (2003)

For verification of the implemented model of Enders et al. (2014) the following test item and parameter settings were used:

Part Nr. (ID)	Test 1001
Lead time (CSC)	73
h (CSC)	1
Demand rate/year	100
Fraction Class 1	0,5
Fill rate (Class 1)	97,0%
Fill rate (Class 2)	90,0%

Table 11.16: Test item with input variable values for CSC

These settings led the model to determine an order-up-to level $S = 29$ and a critical level $c = 1$. Manually the following tables with probabilities were calculated:

j	0	1	2	3	4	5	6	7	8
x 29	0,006258	0	0	0	0	0	0	0	0
30	0,004172	0,002086	0	0	0	0	0	0	0
31	0,002019	0,002019	0,000673	0	0	0	0	0	0
32	0,000841	0,001262	0,000841	0,00021	0	0	0	0	0
33	0,000319	0,000637	0,000637	0,000319	6,37E-05	0	0	0	0
34	0,000112	0,000281	0,000375	0,000281	0,000112	1,87E-05	0	0	0
35	3,75E-05	0,000112	0,000187	0,000187	0,000112	3,75E-05	5,35E-06	0	0
36	1,19E-05	4,16E-05	8,33E-05	0,000104	8,33E-05	4,16E-05	1,19E-05	1,49E-06	0
37	3,62E-06	1,45E-05	3,38E-05	5,07E-05	5,07E-05	3,38E-05	1,45E-05	3,62E-06	4,02E-07

Table 11.17: Probabilities used for calculation of the fill rate of class 1 orders

j	0
x 28	0,018147
29	0,012515
30	0,008344
31	0,005383
32	0,003364
33	0,002039
34	0,001199
35	0,000685
36	0,000381
37	0,000206
38	0,000108
39	5,56E-05
40	2,78E-05
41	1,35E-05
42	6,45E-06
43	3E-06
44	1,36E-06
45	6,06E-07

Table 11.18: Probabilities used for calculation of the fill rate of class 2 orders

	j	0	1	2	3	4	5	6	7	8
x	29	0	0	0	0	0	0	0	0	0
	30	0	0,002086	0	0	0	0	0	0	0
	31	0	0,002019	0,001346	0	0	0	0	0	0
	32	0	0,001262	0,001682	0,000631	0	0	0	0	0
	33	0	0,000637	0,001274	0,000956	0,000255	0	0	0	0
	34	0	0,000281	0,00075	0,000843	0,00045	9,37E-05	0	0	0
	35	0	0,000112	0,000375	0,000562	0,00045	0,000187	3,21E-05	0	0
	36	0	4,16E-05	0,000167	0,000312	0,000333	0,000208	7,14E-05	1,04E-05	0
	37	0	1,45E-05	6,75E-05	0,000152	0,000203	0,000169	8,68E-05	2,53E-05	3,22E-06

Table 11.19: Table used for calculation of the average number of backorders of class 1 orders

	j	0
x	28	0
	29	0,006258
	30	0,008344
	31	0,008074
	32	0,006729
	33	0,005097
	34	0,003598
	35	0,002399
	36	0,001523
	37	0,000926
	38	0,000542
	39	0,000306
	40	0,000167
	41	8,81E-05
	42	4,52E-05
	43	2,25E-05
	44	1,09E-05
	45	5,15E-06

Table 11.20: Table used for calculation of the average number of backorders of class 2 orders

Applying the calculations described in section 6.1 the following output values can be calculated:

Output variable	Manual calculation	Model output
Fill rate (Class 1)	97,52%	97,52%
Fill rate (Class 2)	94,75%	94,75%
Holding costs/year	€ 9,06	€ 9,06

Table 11.21: Output values at CSC for test part

Appendix J Validation through simulation

In order to validate the model, simulations have been run with the same test cases that were used for the manual calculations (Appendix I). The demand processes were generated randomly according to a Poisson process with the same mean as the model input. The model consists of two separate models. For the validation of the model of the RSHQ, the order-up-to level of the CSC was fixed to 1000, in order to represent an ample supplier and only demand of this RSHQ was generated. For the validation of the CSC-model, the demand has only been generated for the CSC and no demand for the RSHQ's. After the validation under Poisson demand, the assumption that the demand follows a Poisson process is tested with demand data generated from the actual observed demand. With the same demand data the 'Batching' solution is tested on its validity.

Model of CSC (Deshpande et al., 2003)

The model generates an S-level of 29 and a c-level of 1 for the test case (Table 11.16). In Table 8.1 the results of the simulation can be found. The confidence interval is based on the student-t distribution with 19 degrees of freedom. From this simulation it can be concluded that the hypotheses that the fill rates and the total costs of the simulation are equal to the fill rates and the total costs of the model are all not rejected. The model assumes continuous review, whereas this is periodic review with a review period of 1 day. It can be concluded from this simulation that this approximation in the model of the reality does not have a significant impact.

Simulation	Beta1	Beta2	Total costs
1	93,96%	89,59%	€ 7,95
2	97,05%	89,07%	€ 8,43
3	99,90%	99,36%	€ 10,40
4	99,73%	94,26%	€ 9,59
5	97,66%	97,61%	€ 10,22
6	98,61%	95,78%	€ 9,02
7	98,52%	95,78%	€ 8,92
8	92,85%	87,55%	€ 6,74
9	97,75%	92,33%	€ 8,64
10	99,42%	98,61%	€ 9,13
11	99,19%	96,34%	€ 9,18
12	99,37%	97,54%	€ 9,27
13	95,27%	92,31%	€ 7,89
14	99,75%	98,04%	€ 9,51
15	98,28%	96,10%	€ 7,92
16	99,07%	95,69%	€ 8,61
17	98,64%	96,40%	€ 8,73
18	98,23%	92,79%	€ 7,89
19	99,64%	95,83%	€ 8,71
20	98,00%	89,96%	€ 8,48
Average	98,04%	94,55%	€ 8,76
Model	**97,52%**	**94,75%**	**€ 9,06**
Lower bound Conf int.	97,14%	92,95%	€ 8,36
Upper bound Conf int.	98,95%	96,15%	€ 9,16

Table 11.22: Simulation results for CSC-model with confidence intervals (α=0,05)

Model of RSHQ (Enders et al., 2014)

The model generates an S-level of 3 and a c-level of 1 for the test case (Table 11.13). In Table 11.23 the results of the simulation can be found. The confidence interval is based on the student-t distribution with 19 degrees of freedom. From this simulation it can be concluded that the hypotheses, that the fill rates and all of the cost parts of the simulation are equal to the fill rates and the cost parts of the model, are all not rejected. The model assumes continuous review, whereas this is periodic review with a review period of 1 week. It can be concluded from this simulation that this approximation in the model of the reality does not have a significant impact.

Simulation	Beta1	Beta2	Holding costs	Transp. cost	Emerg. costs	Total costs
1	100,00%	95,92%	€ 2,57	€ 9,60	€ 0,00	€ 12,17
2	97,66%	93,48%	€ 2,50	€ 11,37	€ 1,62	€ 15,49
3	95,74%	89,66%	€ 2,61	€ 8,76	€ 1,62	€ 12,99
4	100,00%	90,16%	€ 2,55	€ 10,11	€ 0,00	€ 12,66
5	100,00%	94,44%	€ 2,60	€ 9,26	€ 0,00	€ 11,86
6	100,00%	95,24%	€ 2,49	€ 11,37	€ 0,00	€ 13,86
7	98,55%	83,33%	€ 2,44	€ 13,05	€ 0,81	€ 16,30
8	98,33%	89,09%	€ 2,58	€ 9,69	€ 0,81	€ 13,08
9	100,00%	86,67%	€ 2,59	€ 9,52	€ 0,00	€ 12,10
10	100,00%	94,67%	€ 2,48	€ 11,79	€ 0,00	€ 14,26
11	100,00%	91,67%	€ 2,58	€ 9,77	€ 0,00	€ 12,35
12	100,00%	93,75%	€ 2,53	€ 10,78	€ 0,00	€ 13,31
13	100,00%	83,61%	€ 2,55	€ 10,44	€ 0,00	€ 12,99
14	100,00%	85,09%	€ 2,54	€ 10,61	€ 0,00	€ 13,15
15	100,00%	89,83%	€ 2,54	€ 10,61	€ 0,00	€ 13,15
16	100,00%	90,00%	€ 2,64	€ 8,00	€ 0,00	€ 10,65
17	100,00%	95,45%	€ 2,54	€ 10,19	€ 0,00	€ 12,74
18	100,00%	90,18%	€ 2,57	€ 9,69	€ 0,00	€ 12,26
19	98,39%	93,86%	€ 2,55	€ 10,11	€ 0,81	€ 13,47
20	100,00%	92,59%	€ 2,51	€ 11,20	€ 0,00	€ 13,71
Average	99,43%	90,93%	€ 2,55	€ 10,30	€ 0,28	€ 13,13
Model	**99,40%**	**91,63%**	**€ 2,53**	**€ 10,44**	**€ 0,30**	**€ 13,27**
Lower bound Conf int.	98,86%	88,96%	€ 2,52	€ 9,72	€ 0,01	€ 12,50
Upper bound Conf int.	100,01%	92,90%	€ 2,57	€ 10,87	€ 0,56	€ 13,76

Table 11.23: Simulation results for RSHQ-model with confidence intervals (α=0,05)

Combined model

The models of the CSC and the RSHQ's have been combined with an iterative approach and an approximation of the lead time for the RSHQ. The model calculates an S-level of 7 and a c-level of 1 for the RSHQ and an S-level of 31 and a c-level of 1 for the CSC. The simulation results can be found in Table 11.24 for the fill rates and in Table 11.25 for the costs. The expected fill rates and costs at the CSC and the total costs at the RSHQ are within the bandwidth of the confidence interval of the simulation. The expected fill rates of the RSHQ are below the lower bound found by the simulation and the expected total costs of the network are higher than the upper bound found by the simulation. This implies that the model underestimates the performance of the system. This is not perfect for validation, but from a designer's point of view it is fine. Although the model does not perfectly fit to the reality it makes sure that the functional requirements are met.

Simulation	Beta1 CSC	Beta2 CSC	Beta1 RSHQ	Beta2 RSHQ
1	98,54%	94,53%	100,00%	100,00%
2	97,38%	90,03%	100,00%	100,00%
3	93,02%	78,23%	100,00%	100,00%
4	97,54%	93,77%	100,00%	100,00%
5	97,34%	89,80%	100,00%	100,00%
6	99,24%	95,43%	100,00%	100,00%
7	99,44%	96,33%	100,00%	100,00%
8	98,43%	92,28%	100,00%	100,00%
9	98,92%	98,07%	100,00%	100,00%
10	98,20%	94,75%	100,00%	100,00%
11	98,76%	97,81%	100,00%	100,00%
12	98,98%	97,44%	100,00%	100,00%
13	99,80%	98,08%	100,00%	100,00%
14	96,45%	87,48%	100,00%	100,00%
15	99,85%	96,39%	100,00%	100,00%
16	99,16%	97,54%	100,00%	100,00%
17	94,08%	88,08%	100,00%	95,16%
18	97,45%	93,76%	100,00%	100,00%
19	98,67%	94,94%	100,00%	100,00%
20	96,37%	92,56%	100,00%	100,00%
Average	97,88%	93,36%	100,00%	99,76%
Model	**97,19%**	**93,98%**	**99,43%**	**96,04%**
Lower bound Conf int.	97,04%	91,10%	100,00%	99,25%
Upper bound Conf int.	98,72%	95,63%	100,00%	100,26%

Table 11.24: Simulation results (aggregate fill rates) for combined model with confidence intervals (α=0,05)

Simulation	Hold. RSHQ	Trans. RSHQ	Emer. RSHQ	Tot. costs RSHQ	Tot. costs CSC	Total costs
1	€ 6,52	€ 10,28	€ 0,00	€ 16,80	€ 9,21	€ 26,02
2	€ 6,42	€ 11,63	€ 0,00	€ 18,05	€ 7,96	€ 26,01
3	€ 6,48	€ 10,11	€ 0,00	€ 16,59	€ 6,50	€ 23,09
4	€ 6,50	€ 10,61	€ 0,00	€ 17,11	€ 8,87	€ 25,98
5	€ 6,48	€ 10,61	€ 0,00	€ 17,10	€ 8,20	€ 25,30
6	€ 6,45	€ 12,21	€ 0,00	€ 18,66	€ 9,64	€ 28,29
7	€ 6,55	€ 9,85	€ 0,00	€ 16,40	€ 8,96	€ 25,36
8	€ 6,54	€ 10,19	€ 0,00	€ 16,73	€ 8,52	€ 25,24
9	€ 6,51	€ 10,70	€ 0,00	€ 17,21	€ 9,26	€ 26,46
10	€ 6,48	€ 11,03	€ 0,00	€ 17,51	€ 8,48	€ 26,00
11	€ 6,54	€ 9,86	€ 0,00	€ 16,40	€ 9,20	€ 25,60
12	€ 6,54	€ 9,93	€ 0,00	€ 16,48	€ 9,68	€ 26,16
13	€ 6,55	€ 10,19	€ 0,00	€ 16,74	€ 10,03	€ 26,77
14	€ 6,51	€ 9,60	€ 0,00	€ 16,11	€ 8,79	€ 24,90
15	€ 6,56	€ 9,85	€ 0,00	€ 16,42	€ 9,03	€ 25,45
16	€ 6,59	€ 9,01	€ 0,00	€ 15,60	€ 9,58	€ 25,18
17	€ 6,37	€ 10,61	€ 0,00	€ 16,98	€ 8,03	€ 25,02
18	€ 6,58	€ 8,42	€ 0,00	€ 15,00	€ 8,70	€ 23,69
19	€ 6,46	€ 10,95	€ 0,00	€ 17,41	€ 8,81	€ 26,22
20	€ 6,36	€ 12,64	€ 0,00	€ 18,99	€ 7,93	€ 26,93
Average	€ 6,50	€ 10,41	€ 0,00	€ 16,91	€ 8,77	€ 25,68
Model	**€ 4,54**	**€ 12,43**	**€ 0,29**	**€ 17,26**	**€ 9,08**	**€ 26,34**
LB Conf int.	€ 6,47	€ 9,95	€ 0,00	€ 16,48	€ 8,40	€ 25,16
UB Conf int.	€ 6,53	€ 10,88	€ 0,00	€ 17,35	€ 9,14	€ 26,20

Table 11.25: Simulation results (costs) for combined model with confidence intervals (α=0,05)

Poisson process

The model of the CSC and the RSHQ's both assume a Poisson distribution. This assumption is tested for the combined model with test data generated from the observed demand for one part (part 12). Only the CSC and the RSHQ in the USA are used. The model calculates an S-level of 13 and a c-level of 3 for the RSHQ and an S-level of 531 and a c-level of 39 for the CSC. The simulation results can be found in Table 11.26 for the fill rates and in Table 11.27 for the costs. The costs at the CSC and the total costs at the RSHQ are much lower than the bandwidth of the confidence interval of the simulation. The expected fill rates of the CSC and the RSHQ are both far above the upper bound found by the simulation and the expected total costs of the network are lower than the lower bound found by the simulation. This implies that the model overestimates the performance of the system extremely. This means that the model with the assumption that the demand follows a Poisson process cannot be validated.

Simulation	Beta1 CSC	Beta2 CSC	Beta1 RSHQ	Beta2 RSHQ
1	92,84%	0,00%	4,3%	0,0%
2	95,09%	19,66%	24,4%	16,5%
3	94,75%	0,00%	6,7%	0,0%
4	92,88%	0,00%	6,6%	0,0%
5	93,63%	0,41%	15,6%	1,9%
6	92,41%	0,27%	6,6%	0,9%
7	93,05%	6,11%	11,5%	6,4%
8	94,32%	7,13%	18,2%	9,5%
9	94,81%	9,65%	15,2%	11,4%
10	92,95%	0,00%	7,4%	0,0%
Average	93,67%	4,32%	11,6%	4,65%
Model	**99,90%**	**86,61%**	**99,99%**	**99,11%**
Lower bound Conf int.	92,97%	-0,33%	7,0%	0,4%
Upper bound Conf int.	94,32%	8,63%	15,9%	8,6%

Table 11.26: Simulation results (aggregate fill rates) for Poisson assumption with confidence intervals (α=0,05)

Simulation	Hold. RSHQ	Trans. RSHQ	Emer. RSHQ	Tot. costs RSHQ	Tot. costs CSC	Total costs
1	€ 0,05	€ 1,08	€ 2.856,13	€ 2.857,26	€ 9,40	€ 2.866,65
2	€ 0,75	€ 1,74	€ 2.037,92	€ 2.040,41	€ 14,18	€ 2.054,59
3	€ 0,07	€ 1,23	€ 2.707,08	€ 2.708,39	€ 9,64	€ 2.718,03
4	€ 0,08	€ 1,30	€ 2.515,46	€ 2.516,85	€ 9,40	€ 2.526,25
5	€ 0,25	€ 1,51	€ 2.396,83	€ 2.398,59	€ 9,42	€ 2.408,01
6	€ 0,12	€ 1,31	€ 2.433,33	€ 2.434,76	€ 9,51	€ 2.444,27
7	€ 0,30	€ 1,44	€ 2.253,88	€ 2.255,61	€ 9,52	€ 2.265,13
8	€ 0,44	€ 1,76	€ 2.217,38	€ 2.219,57	€ 10,77	€ 2.230,34
9	€ 0,58	€ 1,52	€ 2.503,29	€ 2.505,40	€ 10,94	€ 2.516,33
10	€ 0,08	€ 1,22	€ 2.253,88	€ 2.255,17	€ 9,32	€ 2.264,49
Average	€ 0,27	€ 1,41	€ 2.417,52	€ 2.419,20	€ 10,21	€ 2.429,41
Model	**€ 4,24**	**€ 4,51**	**€ 0,17**	**€ 8,92**	**€ 30,16**	**€ 39,08**
LB Conf int.	€ 0,10	€ 1,25	€ 2.243,68	€ 2.245,59	€ 9,13	€ 2.256,42
UB Conf int.	€ 0,43	€ 1,56	€ 2.578,37	€ 2.579,84	€ 11,21	€ 2.589,48

Table 11.27: Simulation results (costs) for Poisson assumption with confidence intervals (α=0,05)

'Batching' solution

The 'Batching' solution is an approximation of the demand distribution. This approximation is tested with the same demand data as the assumption of Poisson demand. The model calculates an S-level of 32 and a c-level of 1 for the RSHQ and an S-level of 620 and a c-level of 16 for the CSC. The simulation results can be found in Table 11.28 for the fill rates and in Table 11.27 for the costs. The costs at the CSC and the total costs at the RSHQ are both higher than the bandwidth of the confidence interval of the simulation. The expected fill rates of the CSC and the RSHQ are both below the lower bound found by the simulation and the expected total costs of the network are higher than the upper bound found by the simulation. This implies that the model underestimates the performance of the system. This is not perfect for validation, but from a designer's point of view it is fine. Although the model does not perfectly fit to the reality it makes sure that the functional requirements are met.

Simulation	Beta1 CSC	Beta2 CSC	Beta1 RSHQ	Beta2 RSHQ
1	99,92%	99,02%	100,0%	100,0%
2	99,98%	99,37%	100,0%	100,0%
3	100,00%	100,00%	100,0%	100,0%
4	100,00%	99,80%	100,0%	100,0%
5	99,99%	99,21%	100,0%	100,0%
6	99,98%	98,86%	100,0%	100,0%
7	100,00%	100,00%	100,0%	100,0%
8	100,00%	100,00%	100,0%	100,0%
9	100,00%	100,00%	100,0%	100,0%
10	100,00%	100,00%	100,0%	100,0%
Average	99,99%	99,63%	100,0%	100,00%
Model	99,90%	92,37%	99,89%	98,50%
Lower bound Conf int.	99,97%	99,29%	100,0%	100,0%
Upper bound Conf int.	100,00%	99,93%	100,0%	100,0%

Table 11.28: Simulation results (agg. fill rates) for the approximation with the 'Batching' solution with conf. intervals (α=0,05)

Simulation	Hold. RSHQ	Trans. RSHQ	Emer. RSHQ	Tot. costs RSHQ	Tot. costs CSC	Total costs
1	€ 13,21	€ 4,35	€ 0,00	€ 17,56	€ 59,05	€ 76,61
2	€ 13,35	€ 4,09	€ 0,00	€ 17,44	€ 67,45	€ 84,89
3	€ 13,23	€ 4,36	€ 0,00	€ 17,59	€ 61,06	€ 78,66
4	€ 13,30	€ 4,19	€ 0,00	€ 17,49	€ 65,51	€ 83,01
5	€ 13,29	€ 4,21	€ 0,00	€ 17,50	€ 59,21	€ 76,71
6	€ 13,26	€ 4,23	€ 0,00	€ 17,50	€ 61,45	€ 78,94
7	€ 13,37	€ 4,03	€ 0,00	€ 17,40	€ 68,92	€ 86,32
8	€ 13,25	€ 4,32	€ 0,00	€ 17,57	€ 72,02	€ 89,59
9	€ 13,23	€ 4,33	€ 0,00	€ 17,57	€ 65,66	€ 83,22
10	€ 13,45	€ 3,81	€ 0,00	€ 17,26	€ 68,24	€ 85,50
Average	€ 13,29	€ 4,19	€ 0,00	€ 17,49	€ 64,86	€ 82,34
Model	**€ 13,24**	**€ 4,51**	**€ 2,93**	**€ 20,69**	**€ 72,35**	**€ 93,04**
LB Conf int.	€ 13,24	€ 4,07	€ 0,00	€ 17,41	€ 61,67	€ 79,18
UB Conf int.	€ 13,34	€ 4,31	€ 0,00	€ 17,55	€ 67,81	€ 85,27

Table 11.29: Simulation results (costs) for the approximation with the 'Batching' solution with conf. intervals (α=0,05)

Appendix K Details of choice for transportation mode

In Figure 11.2 the details of the choice for the transportation mode to the RSHQ in the USA (CUSA) can be found. The figure depicts the number of parts shipped with air and sea transportation differentiated per class of weight and volume of the part and per class of demand value. With demand value, the product of the demand rate and the part price is meant. From the graph it can be observed that on the dimension weight, more parts are shipped over sea as the weight increases. The dimension volume is less important for the choice of transport mode. On the dimension demand value, it can be observed that parts with a lower demand value are transported more over sea.

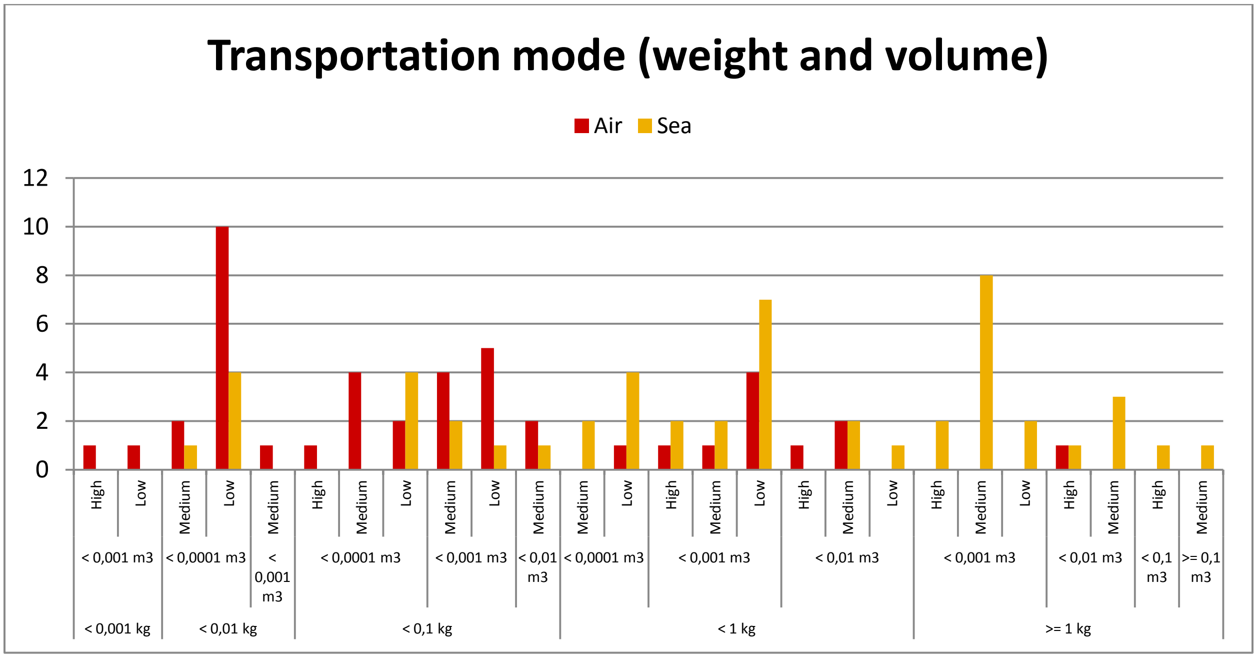


Figure 11.2: Number of parts shipped to RSHQ 1 (CUSA) per weight, volume and demand value class

Appendix L Releasing fill rate constraint class 1 at CSC for Class A3 parts

Table 11.30 shows the effect of decreasing the fill rate constraint for class 1 orders at the CSC for parts that are expensive slow movers (Class A3) below 82,4%. The effect on the costs is larger than the effect on the expected fill rate as can be seen from the graph in Figure 11.3. If the choice would be made to release the fill rate constraints for expensive slow moving items, this could yield €2.063, but then the aggregate fill rate constraint of 97% would not be met anymore. Decreasing the fill rate target to 70% could yield €1.025, while still meeting the aggregate fill rate constraint of 97%.

Target fill rate (Class A3)	Expected aggregate fill rate	Total costs
82,4%	97,23%	€ 64.600
70,0%	97,02%	€ 63.575
60,0%	96,83%	€ 63.274
40,0%	96,34%	€ 62.909
20,0%	95,98%	€ 62.606
0,1%	95,63%	€ 62.533

Table 11.30: Expected aggregate fill rate and total costs for different target fill rates for Class A3

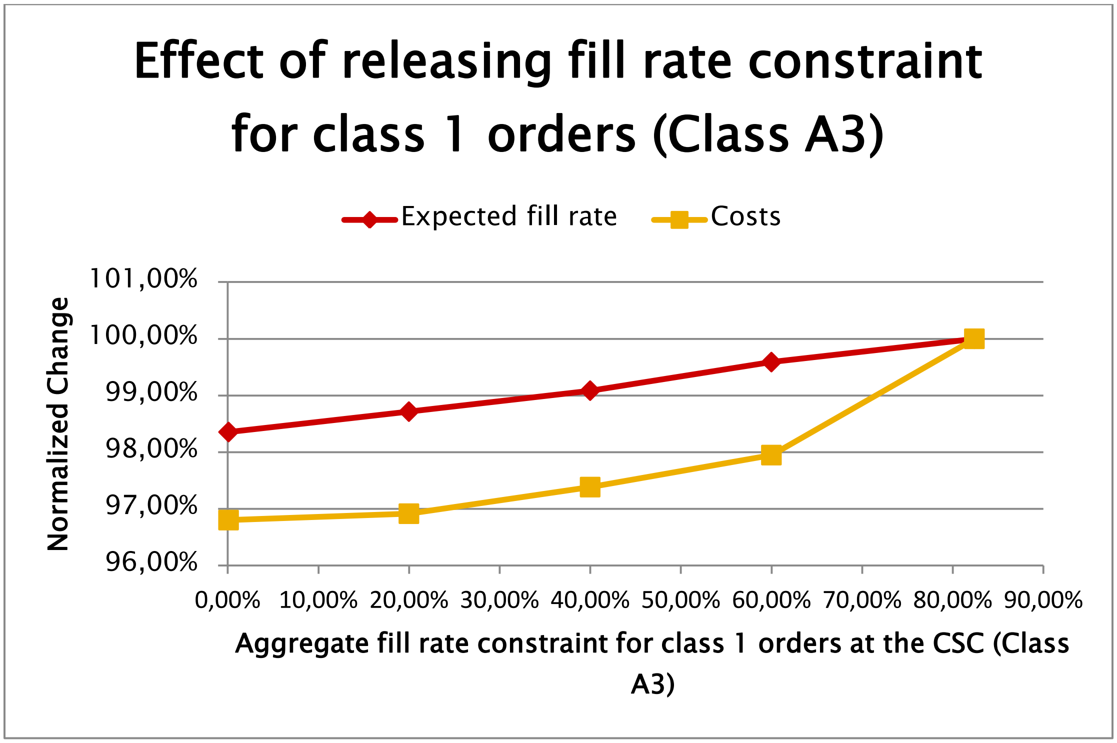


Figure 11.3: Sensitivity analysis of the fill rate constraint for class 1 orders at the CSC for expensive slow movers

Appendix M Sensitivity analysis of class 2 fill rate target (RSHQ)

Changing the target aggregate fill rate for class 2 orders has a significant impact on both the total costs and the expected aggregate fill rate at the RSHQ's. The effect on the total costs is larger when the fill rate increases further than 95%. This is in line with the common theory about the relation between costs and service levels in spare parts inventory management that costs increase exponentially as the fill rate targets are higher. It can be seen from the graph that the aggregate fill rate target for regular replenishment orders at the RSHQ's should be at least 91% in order to meet the target.

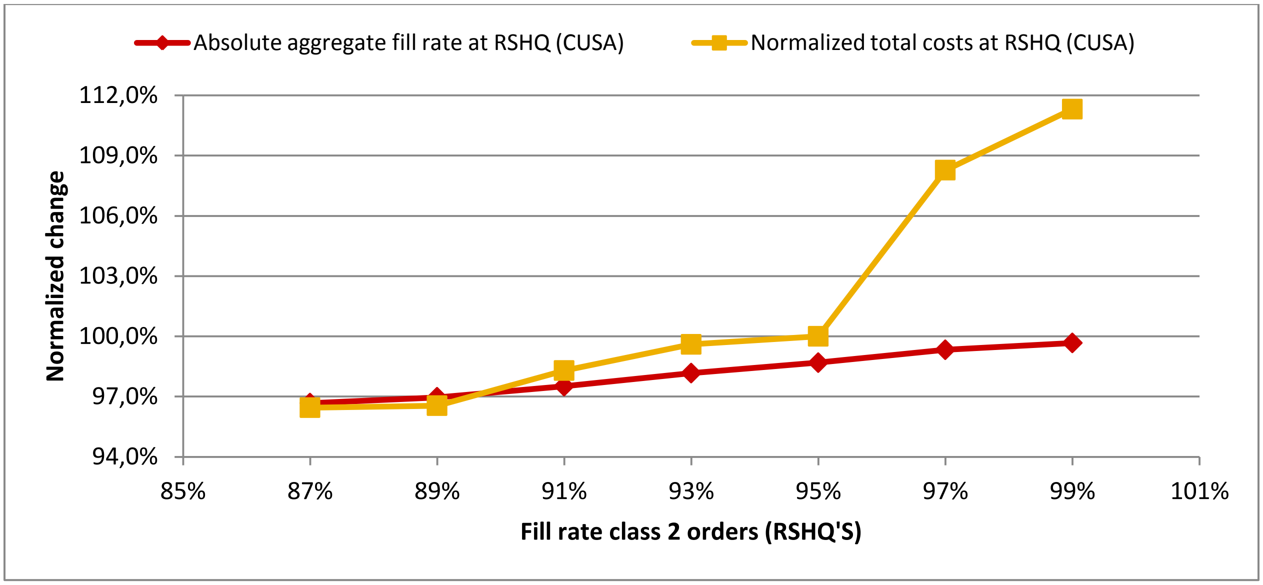


Figure 11.4: Sensitivity analysis on the effect of a change in the target aggregate fill rate for class 2 orders at the RSHQ's

Appendix N Effect of changing holding cost rate on solution

In Table 11.31 the details can be found of the solution for 6 test parts for different holding cost rates. It can be seen that when the holding cost increases, two things may happen:

- Change from Sea to Air: in this case S decreases and the critical level might decrease a little bit as well.
- Decrease in S- and c-level: in this case the S- and c-levels both change. For most of the parts this is with one unit only.

The reason for the change in transportation mode is that the lead time for air shipments is smaller. So if the holding costs increase, it is more attractive to use air shipments in order to decrease the costs for items that are in transit.

The decrease in S- and c-level is caused by the tradeoff between holding costs and costs for emergency shipments. If the holding costs increase, the costs for more emergency shipments become relatively smaller, which causes a lower fill rate for emergency orders to have lower costs in some cases. Therefore the critical level is decreased together with the S-level, which has the effect that the fill rate for emergency orders decreases, and the fill rate for regular orders decreases a lot less.

Holding cost rate	**5%**			**10%**			**15%**			**20%**			**25%**			**30%**		
Item nr.	**S**	**c**	**Sea/ Air**	**S**	**c**	**Sea/Air**	**S**	**c**	**Sea/ Air**	**S**	**c**	**Sea/ Air**	**S**	**c**	**Sea/ Air**	**S**	**c**	**Sea/ Air**
4	24	3	Sea	24	3	Sea	18	3	Air	15	2	Air	15	2	Air	15	2	Air
8	4	2	Air	4	2	Air	4	2	Air	4	2	Air	3	1	Air	3	1	Air
33	9	1	Sea	9	1	Sea	6	0	Air	6	0	Air	6	0	Air	6	0	Air
43	18	3	Sea	18	3	Sea	18	3	Sea	18	3	Sea	18	3	Sea	16	2	Sea
93	5	1	Sea	3	1	Air	3	1	Air	3	1	Air	2	0	Air	2	0	Air
104	92	3	Sea	92	3	Sea	92	3	Sea	88	2	Sea	88	2	Sea	88	2	Sea

Table 11.31: Details of solution for 6 test parts

Appendix O Effect of 'Batching' solution in implementation

In order to make sure that the tool does not crash because of an overflow error and that the computation time stays reasonably low, a solution has been implemented that will be called the 'Batching' solution. The impact of increasing the batch size is analyzed by using several test items. In Table 11.32 and Table 11.33 the input and output for the analysis of the impact of the 'Batching' solution can be found. From the output it can be read that the impact of increasing the batch size is significant. The order-up-to levels increase, the critical levels decrease and the total costs increase as the batch size increases. This effect can be observed for all of the test items.

The effect of the 'Batching' solution on the computation time and expected total costs can be found in Figure 11.5. It can be seen that the total costs almost increase linearly and the effect on the computation time decreases when the batch size increases. For this reason, the 'Batching' solution is implemented in two ways:

- Error handling: if an overflow error occurs, the model automatically augments 1 unit to the batch size.
- Computation time reduction: a maximum value for the 'demand during lead time' for the model can be specified. Since the computation time particularly increases with larger demand during lead time, the batch size is increased if the maximum is exceeded.

In this way, the model does not crash due to overflow errors and the computation time can be reduced if this is preferred by the logistic engineer. A value of 100 units demand during lead time is recommended as this turns out to be around the turning point where the computation time reduction is decreasing less. The average batch size found with this settings for the test data of the ColorWave 600 is 1,5 units with a maximum of 11 units. 85% of the units have a batch size of 1. So it is concluded that only for about 15 % of the parts there is an effect. These are parts with a large demand rate or a large lead time.

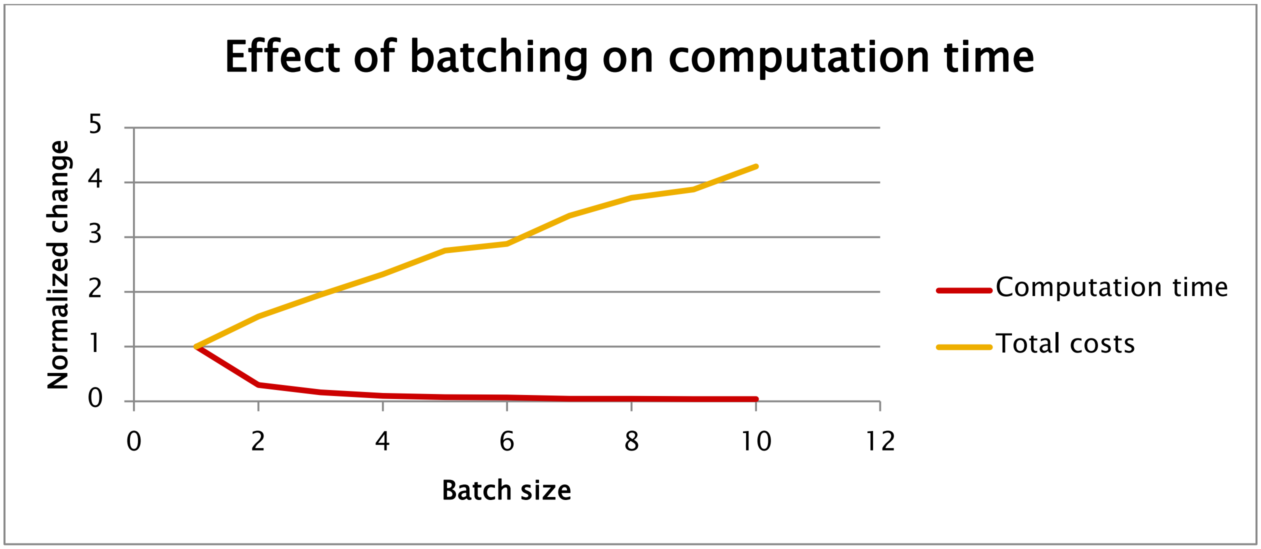


Figure 11.5: Effect of batching on the computation time

Part Nr. (ID)	Lead time (CSC)	h (CSC)	Demand rate/year	Batch size	Fraction Class 1	Fill rate (1)	Fill rate (2)
Test 01	5	1	100	1	0,5	97,0%	90,0%
Test 01	5	1	100	2	0,5	97,0%	90,0%
Test 01	5	1	100	3	0,5	97,0%	90,0%
Test 01	5	1	100	4	0,5	97,0%	90,0%
Test 01	5	1	100	5	0,5	97,0%	90,0%
Test 01	5	1	100	6	0,5	97,0%	90,0%
Test 01	5	1	100	7	0,5	97,0%	90,0%
Test 01	5	1	100	8	0,5	97,0%	90,0%
Test 01	5	1	100	9	0,5	97,0%	90,0%
Test 01	5	1	100	10	0,5	97,0%	90,0%
Test 101	50	1	100	1	0,5	97,0%	90,0%
Test 101	50	1	100	2	0,5	97,0%	90,0%
Test 101	50	1	100	3	0,5	97,0%	90,0%
Test 101	50	1	100	4	0,5	97,0%	90,0%
Test 101	50	1	100	5	0,5	97,0%	90,0%
Test 101	50	1	100	6	0,5	97,0%	90,0%
Test 101	50	1	100	7	0,5	97,0%	90,0%
Test 101	50	1	100	8	0,5	97,0%	90,0%
Test 101	50	1	100	9	0,5	97,0%	90,0%
Test 101	50	1	100	10	0,5	97,0%	90,0%
Test 1001	50	1	1000	1	0,5	97,0%	90,0%
Test 1001	50	1	1000	2	0,5	97,0%	90,0%
Test 1001	50	1	1000	3	0,5	97,0%	90,0%
Test 1001	50	1	1000	4	0,5	97,0%	90,0%
Test 1001	50	1	1000	5	0,5	97,0%	90,0%
Test 1001	50	1	1000	6	0,5	97,0%	90,0%
Test 1001	50	1	1000	7	0,5	97,0%	90,0%
Test 1001	50	1	1000	8	0,5	97,0%	90,0%
Test 1001	50	1	1000	9	0,5	97,0%	90,0%
Test 1001	50	1	1000	10	0,5	97,0%	90,0%
Test 201	50	1	100	1	0,5	80,0%	50,0%
Test 201	50	1	100	2	0,5	80,0%	50,0%
Test 201	50	1	100	3	0,5	80,0%	50,0%
Test 201	50	1	100	4	0,5	80,0%	50,0%
Test 201	50	1	100	5	0,5	80,0%	50,0%
Test 201	50	1	100	6	0,5	80,0%	50,0%
Test 201	50	1	100	7	0,5	80,0%	50,0%
Test 201	50	1	100	8	0,5	80,0%	50,0%
Test 201	50	1	100	9	0,5	80,0%	50,0%
Test 201	50	1	100	10	0,5	80,0%	50,0%
Test 301	50	1	100	1	0,75	97,0%	90,0%
Test 301	50	1	100	2	0,75	97,0%	90,0%
Test 301	50	1	100	3	0,75	97,0%	90,0%
Test 301	50	1	100	4	0,75	97,0%	90,0%
Test 301	50	1	100	5	0,75	97,0%	90,0%
Test 301	50	1	100	6	0,75	97,0%	90,0%
Test 301	50	1	100	7	0,75	97,0%	90,0%
Test 301	50	1	100	8	0,75	97,0%	90,0%
Test 301	50	1	100	9	0,75	97,0%	90,0%
Test 301	50	1	100	10	0,75	97,0%	90,0%

Table 11.32: Input for analysis of the effect of the ‘Batching’ solution

Part Nr. (ID)	S	c	Fill rate (Class 1)	Fill rate (Class 2)	Total costs/year
Test 01	5	0	98,69%	98,69%	3,633669029
Test 01	8	0	99,47%	99,47%	6,631737567
Test 01	9	0	98,87%	98,87%	7,63428269
Test 01	12	0	99,48%	99,48%	10,63200742
Test 01	15	0	99,72%	99,72%	13,63113398
Test 01	12	0	97,76%	97,76%	10,64076576
Test 01	14	0	98,32%	98,32%	12,63807209
Test 01	16	0	98,69%	98,69%	14,63628593
Test 01	18	0	98,95%	98,95%	16,63504094
Test 01	20	0	99,14%	99,14%	18,63413922
Test 101	21	1	97,21%	93,52%	7,364095107
Test 101	26	0	97,68%	97,68%	12,33861857
Test 101	27	1	97,25%	90,79%	13,43913408
Test 101	32	0	97,61%	97,61%	18,3520757
Test 101	35	0	97,80%	97,80%	21,35144456
Test 101	36	0	97,09%	97,09%	22,37491226
Test 101	42	0	98,49%	98,49%	28,33805021
Test 101	40	1	98,25%	90,50%	26,48997867
Test 101	45	0	98,04%	98,04%	31,35539993
Test 101	50	0	98,69%	98,69%	36,33669029
Test 1001	156	3	97,08%	90,58%	19,29965467
Test 1001	166	2	97,02%	92,38%	29,35247466
Test 1001	174	2	97,44%	92,39%	37,41191861
Test 1001	180	2	97,47%	91,72%	43,51191836
Test 1001	185	2	97,44%	90,90%	48,62463271
Test 1001	192	1	97,05%	94,05%	55,4841759
Test 1001	196	2	97,80%	90,60%	59,72989284
Test 1001	208	0	97,29%	97,28%	71,31264046
Test 1001	207	1	97,35%	94,00%	70,56743717
Test 1001	210	1	97,21%	93,52%	73,64095107
Test 201	17	1	83,52%	69,88%	3,759291124
Test 201	18	1	82,10%	62,12%	5,10633941
Test 201	21	0	82,25%	82,25%	7,797938517
Test 201	20	1	82,74%	55,30%	7,567037919
Test 201	25	0	85,69%	85,69%	11,76150837
Test 201	24	0	80,28%	80,28%	11,04006541
Test 201	28	0	86,48%	86,48%	14,78528412
Test 201	32	0	90,50%	90,50%	18,63029763
Test 201	27	0	80,33%	80,33%	14,14795873
Test 201	30	0	84,07%	84,07%	16,97149039
Test 301	22	0	97,65%	97,65%	8,329586854
Test 301	26	0	97,68%	97,68%	12,3386636
Test 301	30	0	98,13%	98,13%	16,33558218
Test 301	32	0	97,61%	97,61%	18,35210768
Test 301	35	0	97,80%	97,80%	21,35151209
Test 301	36	0	97,09%	97,09%	22,37498124
Test 301	42	0	98,49%	98,49%	28,33806975
Test 301	40	1	97,55%	90,50%	26,43473652
Test 301	45	0	98,04%	98,04%	31,35539243
Test 301	50	0	98,69%	98,69%	36,33672799

Table 11.33: Output for analysis of the effect of the 'Batching' solution

Appendix P Effect of not knowing the customer classes

At the moment only the RSHQ in the USA (CUSA) keeps track of the customer class of incoming orders. In the test case, the fraction of demands that are emergency requests is copied for the other RSHQ's from CUSA. Here the effect is examined for a randomly chosen part if for one RSHQ all demand is specified to be emergency demand or regular replenishment orders or if the actual fraction is used. To this end a simulation has been run with the output parameters of the model for the three cases. The same generated demand was used for all cases (original fraction, only emergency, only regular). In Table 11.34 the results are given. It can be seen that in every simulation the costs were higher if the demand was all classified to be the same in the model. If the demand is all specified as emergency demand, the total costs are at least 4% higher and if the demand is all specified as regular replenishment order, the total costs become more than 10 times as high as they could be. The fill rates are higher if all demand is classified as emergency request and lower if all demand is classified as regular replenishment. Another interesting observation is that the cost change is in any case at the RSHQ. This means that if the RSHQ's do not specify the customer class, they only hurt themselves.

	Simulation	Beta1 RSHQ	Beta2 RSHQ	Costs RSHQ	Costs CSC	Total Costs
CUSA fractions	1	100,00%	94,85%	€ 0,85	€ 0,60	€ 1,45
	2	100,00%	95,36%	€ 0,86	€ 0,51	€ 1,37
	3	100,00%	95,24%	€ 0,85	€ 0,52	€ 1,37
	4	99,66%	93,79%	€ 4,48	€ 0,68	€ 5,15
	5	100,00%	94,52%	€ 0,83	€ 0,63	€ 1,46
Only class 1	1	100,00%	100,00%	€ 0,91	€ 0,60	€ 1,51
	2	100,00%	100,00%	€ 0,92	€ 0,51	€ 1,43
	3	100,00%	100,00%	€ 0,92	€ 0,52	€ 1,44
	4	99,32%	99,31%	€ 8,19	€ 0,68	€ 8,86
	5	100,00%	98,63%	€ 0,89	€ 0,63	€ 1,52
Only class 2	1	98,81%	94,85%	€ 15,45	€ 0,60	€ 16,05
	2	98,16%	98,01%	€ 26,41	€ 0,51	€ 26,92
	3	96,79%	97,62%	€ 37,35	€ 0,52	€ 37,87
	4	95,27%	95,86%	€ 51,92	€ 0,68	€ 52,60
	5	96,60%	94,52%	€ 44,62	€ 0,63	€ 45,25

Table 11.34: Simulation results for three cases (actual, all emergency, all regular) for one randomly chosen part (Part 4)