MASTER

Multi-item, multi-location stock control with capacity constraints for the fieldstock of service parts at Océ

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Abstract

This master thesis describes how the control of service parts in the fieldstock of Océ can be improved. The analysis of the current inventory and fieldstock management revealed that the investment in inventory seems to be unbalanced due to a lack of integral guidelines. Therefore, a multi-location, multi-item stock control model with capacity constraints has been developed, which determines basestock levels at all locations such that the total relevant costs are minimized and target service levels are met. Several situations have been tested to calculate the consequences of tactical decisions.

Preface

This thesis marks the end of my graduation project, and the end of my life as a student. This challenging project at Océ gave me the opportunity to experience the ins and outs of a large and interesting organisation. I was able to see service parts logistics in the real world, which is somewhat different than the world I have studied during the courses at the university. It made this project a valuable experience.

This thesis would not have been possible without the help of several people, who I would like to thank. I want to thank Aafke van Boekel for her enthusiasm and for her constructive and challenging feedback. I thank Rob Olsthoorn for his useful input, and for the knowledge he shared with me. Furthermore, I want to thank everybody who helped me executing this project within Océ; people within LSP, the employees of the operating companies, and the employees involved in the service parts meetings. Their input was very valuable.

Furthermore, I would like to thank my university supervisors. I thank Twan Geenen for his support and the help during this graduation project. He challenged me to structure my project, and with his critical questions he pushed me to rethink every aspect of this project. I would like to thank Geert-Jan van Houtum for his help with the development of the program, and the mathematical support.

Last, but certainly not least, I want to thank my family and friends for their support and friendship, not only during this project, but for the entire period I have spent at university. Without their support, I could not have been where I am now.

Paul Rijk

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Management Summary

Océ is one of the leading companies in printing and document management. Within Océ, there is a strong focus on service; in 2006, 71% of the total revenues were generated by services, consumable materials, interest and business services. To provide service, it is also required to have service parts available that can be used to repair machines. The service parts supply chain in Europe is supplied from the Regional Supply Centre (RSC) in Venlo, with different types of replenishment. This project focuses on Direct Replenishment (DR), which means that all fieldstock locations are supplied directly from the RSC. The fieldstock consists of Quick Response Stocks (QRS's) and carstocks.

Within Océ, several Centrally Managed Logistics (CML) projects are being executed. The goal of the CML-projects is to reduce total costs by improving visibility in the supply chain. The consequences for the service parts supply chain are that the fieldstock inventories of DR-Operating Companies (OpCo's) will be controlled by the department of Logistics Service Parts (LSP). Therefore, the initial goal of this project was to develop a method that can be used to control the fieldstock inventory efficiently.

Analysis

To explore the initial goal of the project, and the problems related to the current situation, interviews were conducted with stakeholders related to the service parts supply chain. This resulted in a problem cluster in which all problems related to the service parts supply chain are stated. The problem cluster leads to the following analysis assignment;

Analyse whether the fieldstock inventory of service parts of Océ is unbalanced and whether this is caused by unclear fieldstock guidelines or by other factors mentioned in the problem cluster.

To execute this assignment, two types of analyses have been executed; an analysis of the current fieldstock inventory, and an analysis of the fieldstock management. The analyses have been executed for the OpCo's Germany, Belgium, Spain and Norway.

For the inventory analysis, four possible consequences of an unbalanced inventory have been analysed. These analyses have been executed by using the value and the total demand for each service part. This resulted in the following analyses and conclusions;

1. Number of urgent orders. This analysis revealed that a significant amount of the urgently ordered service parts have a high value and low demand. This seems to be the right strategy, because it may be more expensive to store these service parts in the fieldstock compared to the costs of urgently ordering these parts.
2. Number of second visits due to parts. Currently, no specific target is set for the total number of second visits due to service parts. However, there are no parts that cause a high number of second visits. This includes service parts that are stored in the fieldstock as well as service parts that are not stored in the fieldstock.
3. Investment in service parts. For this, three analyses have been executed;
   a. The investment in parts stored in the QRS's. Although the average value of the service parts in the QRS is higher than the value of the service parts in the carstocks, all different sorts of parts are stored in the QRS's.
   b. The investment in parts stored in the carstocks. The average value of the service parts stored in the carstocks is lower than the value of the parts stored in the QRS. However, the high value service parts determine a large portion of the total carstock value. For some of these parts it may be better to store them in the QRS.
   c. A significant amount of the service parts stored in the fieldstock hardly generated demand, or did not generate any demand at all, during the analysis period of one year.
4. Risk of obsolescence. The total risk of obsolescence is limited. Although there is a significant amount of service parts that have an End Of Service (EOS)-date that is in the past, or in the near future, the total value of these parts is limited.

The second part of the analysis, the analysis of the fieldstock management, also consists of four analyses;

1. Differences in assortment. There are significant differences in demand for service parts between the OpCo's. The differences in demand do not influence the fieldstock management within an OpCo, but it has consequences for the inventory management at the RSC, because a significant amount of service parts has a low demand.
2. Stock exchange between OpCo's. Currently, no stock exchange takes place between OpCo's on an operational basis. Although this stock exchange may result in a more balanced fieldstock inventory, this is only applicable for high-density areas near the border.

3. Fieldstock inventory guidelines. Most OpCo's use the carstock model to manage the carstocks. This model has a single-item approach, and therefore weighs the costs of keeping a part on stock and the costs of second visits. For the QRS-management, no structured method is available. This means that no method is available for the integral optimisation of the carstocks and QRS's.
4. EOS-management. OpCo's have the opportunity to influence the EOS-management by Océ headquarters. This seems to be sufficient, because the total value of service parts with an EOS-date in the past is limited.

Based on these analyses the following conclusion was drawn; the fieldstock inventory service parts of Océ seems to be unbalanced with regard to the investment in service parts. In the QRS's, all sorts of service parts are stored, and a significant amount of the inventory of service parts in the fieldstock generates no demand, or hardly any demand. The most probable cause for the unbalanced investment in parts is that the current fieldstock guidelines do not optimise the entire fieldstock, with regard to a target service level. For the carstock model and QRS guidelines, it is not known whether these guidelines are (close to) optimal with regard to the integral fieldstock costs.

Design

To overcome the problems stated in the previous section, the following design assignment was defined:

Design a model to overcome the unbalanced investment in fieldstock inventory. This model should optimise the inventory in the fieldstock with regard to all relevant costs and a target service level. The model must be adjustable by OpCo's to a certain extent. Therefore, an implementation plan should specify how to implement the model.

To execute this assignment, an optimisation program was developed that is based on a multi-location model of Kranenburg (2006). This program calculates basestock levels for all fieldstock locations and service parts such that total relevant costs are minimized and a target first visit fill rate is met. The costs taken into account are costs related to inventory keeping, costs related to lateral transhipments and the extra costs of an urgent order compared to a normal order.

The optimisation program uses the first visit fill rate as service measure. The first visit fill rate means that a technician must be able to deliver a specific amount of the demand within the time frame of the first visit. Therefore, the service part should be located in the technician's carstock, a QRS that can be reached within the time frame of the first visit, or in another fieldstock location that is close by.

The program has a 'greedy' approach, which means that a mean aggregate service level is taken into consideration, and not the service levels of individual parts. Customers are concerned by the maintenance of machines, and not the maintenance of individual parts. In general, this approach results in the situation that more low value service parts are stored compared to the high value service parts. To overcome a low first visit fill rate for high value machines, the program makes it possible to adjust the target first visit fill rate for each machine or group of machines.

This program has been programmed in Delphi and successfully verified and validated. The validation took place with three carstocks for which the actual demand and delivery dates for service parts were obtained. The optimisation program calculated different basestock levels, based on a specific target first visit fill rate. These basestock levels were used as input for the validation model. The resulting first visit fill rates were close to the first visit fill rates used as input for the optimisation program. This validates the optimisation program.

Furthermore, an evaluation program has been built. This evaluation program can be used to evaluate actual fieldstock configurations, and may be used to evaluate the performance of different OpCo's.

Results

The performance of the optimisation program was compared with the actual performance of two regions. The configuration of parts advised by the program resulted in total costs that are 93% lower than the costs for the current configuration. Furthermore, the average first visit fill rate was higher. The second case study leads to total relevant costs that are 89% lower.

To achieve these savings, a higher investment in service parts is required. This is because the urgent order costs and lateral order costs have a large influence on the outcomes of the program. These costs are higher than the costs for inventory keeping, and therefore the program advises to store more high value service parts. This results in high first visit fill rates in all cases. However, the first visit fill rates for machines with high-value parts with a lower demand are lower. Therefore, it is required to set a specific target first visit fill rate for these machines.

Different fieldstock scenarios have been tested. These tests lead to the following conclusions:

- Fieldstock settings with a QRS outperform the settings without QRS in most cases. In some cases, extra lateral transhipments between carstocks lead to a better performance. However, it is questionable whether these cases are realistic.
- The current carstock size results in relatively low total relevant costs. In the theoretical case of an unlimited carstock size, a small increase in performance is possible.
- Decreasing the replenishment frequency leads to a large increase of the total relevant costs. An increase in lead-time from 1,5 days to 3 days leads to an increase of total relevant costs equal to 40%. The large cost increase is caused by the limited carstock size. More lateral transhipments are required, which increase the total relevant costs. If Océ wants to decrease the replenishment frequency, the cost savings of this decrease need to be compared with the increase in total relevant fieldstock costs.

Implementation
To gain support for the optimisation program, several actions have been executed during the project. Stakeholders were able to express their opinion and needs with regard to the fieldstock model. To gain further support, it is required that key users understand the program, and that the program is easy to use. To a large extent, this depends on the implementation in the IT-systems. Furthermore, implementing the optimisation program for the service parts supply chain controlled by LSP as well as for the supply chain controlled by Poing would increase the support for the program further.

The implementation should start with a pilot project in one region, after which the program is evaluated, and the required changes in the IT-systems are evaluated. If the tests are successful, the program can be implemented in the IT-systems, and a roll-out in all DR-OpCo's can take place. For the DR3-OpCo's it is required that LSP has access to the program, because LSP is accountable for the fieldstocks of these OpCo's. The program can also be used to benchmark different OpCo's. For a good performance of the program itself, it is required to collect all data in a structured way. Thereby data should be gathered at the organisational units that are responsible for those data.

Conclusions and recommendations
Besides the improvement in performance, there are other advantages with regard to the optimisation program:

- The program makes it possible to set different target service levels for different machine groups.
- The OpCo's did not have a tool to control the QRS inventories. This program overcomes this issue.
- The program makes it possible to calculate the effects of changing parameters. If changes in the supply chain need to be made, the program can calculate the consequences of these changes.
- The evaluation program makes it possible to make a fair benchmark analysis of OpCo's.

With regard to the optimisation program, and DR3-development in general, some organisational issues are relevant as well:

- The program has a total cost approach. Within Océ, these costs are incurred at different organisational units. It would be wise to make one unit responsible for all relevant costs. This prevents sub optimality within the supply chain, and makes it possible to have good CML.
- Within the DR3-concept, it is not known which organisational unit is responsible for which part of the supply chain, and how each unit should be evaluated. No clear performance measures are defined yet, making it hard to evaluate the performance of the supply chain and the organisational units.

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Introduction

This master thesis describes the execution of the graduation project in which a fieldstock control model was developed for the service parts supply chain of Océ. To execute the graduation project, the regulative cycle of Van Strien (1975) was used to structure the project. The regulative cycle can be found in Figure 1.

The regulative cycle is used in projects in which efficiency improvement in an organisation is the final goal. This is also the case for this project, which should result in lower supply chain costs. Within Océ there is a focus on reducing costs. This is also the reason that Rokus van Iperen, Chairman of the Board of Executive Directors made the following statement in the third quarterly report of 2007: *"... we will with high priority reduce total costs and working capital, especially inventories."* This project should help Océ with reducing total costs.

This thesis starts with an introduction about Océ and the service parts supply chain in Chapter 1. The regulative cycle starts in Chapter 2 with the exploration of the cluster of related problems at Océ (step 1). This step was executed by conducting interviews with stakeholders and reading documentation about the problems related to the service parts supply chain. Therefore, the cluster of problems is described in Chapter 2. Chapter 2 also contains the problem definition, and a description of the context of this problem. The third step in the cycle of Van Strien includes the analysis and diagnosis. For this graduation project, the analysis is divided into two parts; an analysis of the fieldstock inventory in Chapter 3, and an analysis of the fieldstock management in Chapter 4.

The design phase of the graduation project starts in Chapter 5 with the description of the design assignment. The design assignment is based on the diagnoses stated in Chapters 3 and 4. Chapter 6 describes the stock control model that is designed to optimise the fieldstock management. This means that the model optimises the fieldstock inventories with regard to a target service level. Chapter 7 translates this model into an optimisation program, and this program is compared with the current situation and tested for several settings in Chapter 8.

Although the implementation is not part of this graduation project, an implementation plan is given in Chapter 9. It describes how the optimisation program should be implemented within Océ. Chapter 10 concludes this graduation report with the main conclusions and recommendations. The evaluation of the project can only take place if the program is implemented, and is in this case thus not yet possible. However, Chapter 8 can be considered as an estimation of the evaluation of the program, because it compares the current performance with the performance that would result from the optimisation program.

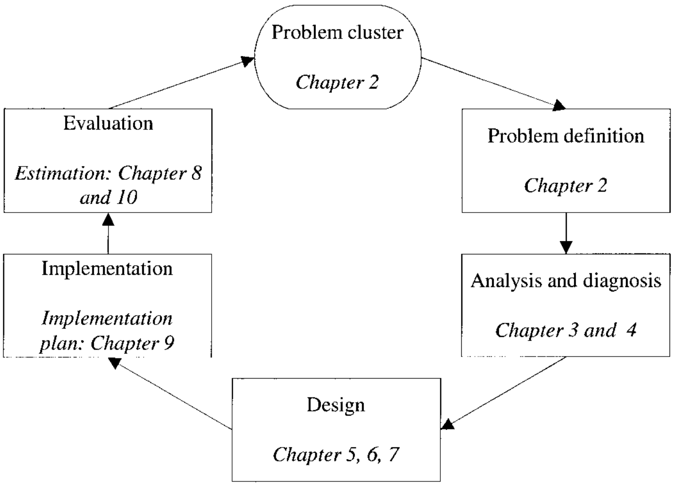


Figure 1; the regulative cycle of Van Strien

1. Company description

This chapter describes the background of the graduation project. Therefore, a short description is given about Océ in Sections 1.1 and 1.2. In Section 1.3 the service parts supply chain within Océ is described, followed by a description of Logistics Service Parts in Section 1.4. Finally, Section 1.5 discusses the direct replenishment principle.

1.1. Historical context

In 1877, chemist Lodewijk van der Grinten began the production of butter-colouring agents. These agents were used to colour butter and margarine. In 1920, Lodewijk's grandson, Louis, started the company's document-copying activities. Initially he produced blueprint paper, which was used to reproduce documents in the 1920s. Louis managed to overcome the problems that were common for this type of copying and thereby he developed an easy and inexpensive method to produce the so-called diazo paper. He called this method of copying Océ (Ohne Componente).

In 1935, Océ developed a diazo application that made it cheaper and easier to make copies. After 1945, electro photographic copying became wide spread, and Océ began developing other products. In 1958 the company went public on the Amsterdam Stock Exchange, began several acquisitions and mergers, and expanded all over the world. During the years hereafter, the company grew steadily through extensive research and strategic alliances. During the 1960s, the copying-market expanded rapidly because of the introduction of electrostatic copiers. The company changed its name from Van der Grinten NV to Océ-van der Grinten NV. In 1997, the company changed its name into Océ.

1.2. Recent developments

Today, Océ operates in the entire chain of professional printing systems; from Research and Development (R&D) and manufacturing to financing and service. In 2006, the total revenues were equal to € 3,1 billion, resulting in a net income of € 57 million. Océ's headquarters is based in Venlo, which hosts most of the R&D and marketing activities. The company employs around 24.000 people in 90 countries. In 30 countries Océ has an own sales organisation, or Operating Company (OpCo). 48% of the revenues are generated in Europe, 46% in the USA, and 6% comes from the rest of the world (Annual report Océ, 2006). In the wide format market, Océ is the global leader, in other markets Océ is one of the top-five companies. The main competitors for Océ are companies like Xerox, Nashuatec, Canon, and Ricoh.

Océ also offers products from other print manufacturers in order to be able to offer a complete product and service range. Océ distinguishes between non-recurring revenues like sales of machines and software, and recurring revenues from services, consumable materials, interest and business services. In 2006, 71% of the revenues were recurring, showing that Océ is a service-orientated organisation. This is also emphasized in the mission statement, which is formulated as follows (Annual report Océ, 2006):

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

To execute this mission, Océ has two strategic market-based business units; Wide Format Printing Systems (WFPS) and Digital Document Systems (DDS). The strategic business unit WFPS produces wide format printers for production, workgroup and office environments. Customers are organisations like construction, architectural and engineering companies. The strategic business unit DDS produces high-volume printers used in, for example, telecom companies, financial institutions and government organisations. Recently, a change in organisational structure was announced, whereby four specialised business units are introduced; Production Printing for mailing companies and commercial print providers, Document Printing for office copying and printing, Wide Format Printing for technical documentation, display graphics and media, and Business Services for corporate applications.

Besides the two business units, the department of Manufacturing and Logistics (M&L) is responsible for the manufacturing of machines, and the logistical processes within Océ. Within M&L, the department of Logistics Service Parts manages the service parts supply chain. The entire organisational structure of Océ and M&L can be found in Appendix A.

1.3. Service parts supply chain

When an Océ machine breaks down, it is necessary to replace a part in the machine in about 50% of the cases. These parts need to be supplied by the service parts supply chain. Service parts are delivered by internal Océ suppliers or external parties. In the future, more service parts will be delivered by external suppliers, because of increasing outsourcing of production, and the increasing sales of non-Océ machines. For the service parts supply chain itself, there are five relevant types of stocking points (see also Figure 2):

1. The Corporate Supply Centre (CSC) in Venlo; From this location all service parts are supplied to the supply chain. The department of Logistics Service Parts is responsible for the CSC, and thus co-ordinates all incoming and outgoing service parts.
2. The Regional Supply Centres (RSC); The Asian Pacific Warehouse (APW) in Singapore and the warehouse in Columbus (USA) function as RSC's. These warehouses are extra stocking points between the CSC and the stocking points in Asia and the America's. Furthermore, the CSC in Venlo can be considered as RSC for Europe.
3. National Warehouses (NWH); This type of warehouse supplies the technicians in the country where the NHW is located. The NWH's are controlled and owned by the OpCo's. There are national warehouses in Asia, South America, and European countries like Poland, Czech Republic and Bulgaria.
4. Quick Response Stock (QRS); Within a country, these stocking points are used to store parts that need to be within a short time range of the customer, but for which it is not possible or efficient to store in the carstock.
5. The carstock; Each technician has inventory in his/her car. This inventory is used as a first stocking point to repair a machine. Therefore it contains small items, and items with a high demand. The QRS's and carstocks together are also called fieldstock.

Besides these five stocking points Océ also owns the inventory of some customers, and Diagnostic Kits (DIKO's). These DIKO's are special cases that contain several service parts, and can be regarded as small QRS's. There are only a few of these customer stocks and DIKO's in the field, and therefore these stocking points are not taken into account for the project. These are not shown in Figure 2 either.

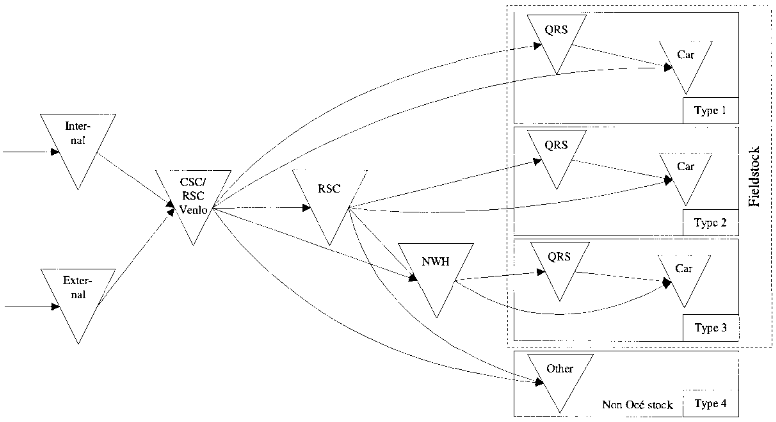


Figure 2: the service parts supply chain

As can be seen in Figure 2, there are four types of delivering service parts from the CSC to the technicians and customers. Each OpCo uses one of these delivery types:

Type 1; Direct replenishment from the CSC Venlo to the fieldstock locations. The subject of this graduation project is related to direct replenishment, and therefore direct replenishment will be explained in more detail in Section 1.5. In this case, the CSC functions as RSC for the fieldstock in Europe.

Type 2; Replenishment from the CSC to a RSC (APW or Columbus). The RSC delivers the parts directly to the fieldstock or sends it to a NWH.

Type 3; Replenishment from the CSC via a NWH to the fieldstock. The NWH delivers the parts to the fieldstock within that OpCo.

Type 4; Replenishment to dealers. In countries without an OpCo, there may be dealers that sell Océ machines. These dealers can also order service parts at the CSC. There are also dealers in countries with an OpCo.

1.4. Logistics Service Parts

As said before, the department of Logistic Service Parts (LSP) controls the CSC and is responsible for the logistical processes with regard to service parts. Therefore LSP works together with the OpCo's and the service departments of the business units. These service departments determine the assortment of service parts, in co-operation with LSP. Furthermore, the business units determine the service levels that have to be met by the service parts supply chain. This means that the OpCo’s as well as LSP have to meet certain service levels. The mission of LSP is formulated as follows (intranet Océ, 2007):

LSP makes sure that a technician never misses a service part.

Within LSP, three main processes are executed: Inventory Control, Warehousing and Customer Service and Support. The organisational structure can be found in Figure 3.

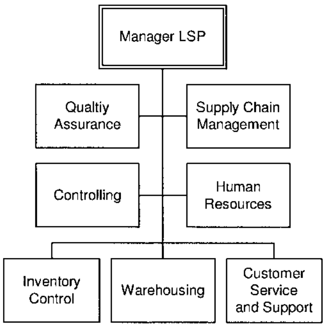


Figure 3; organisational structure Logistics Service Parts (LSP)

The subdepartment Inventory Control (IC) makes sure that sufficient parts are on stock to supply the OpCo’s. This means that IC takes care of the inbound processes; acquisition of the service parts, inventory control for the CSC and life cycle management. Furthermore, IC also controls the inventory in the RSC's and for some of the Direct Replenishment (DR) countries IC also controls the fieldstocks. The processes for these DR-countries are described in more detail in the next section. The subdepartment Warehousing is responsible for the operational warehouse processes within the CSC, and physically handles the orders from OpCo's and other customers. Customer Service and Support (CS&S) takes care of the non-physical outbound processes, meaning that CS&S is responsible for the order management from OpCo’s and other customers.

1.5. Direct replenishment

The graduation project focuses on Direct Replenishment (DR) in Europe, which was shortly described in the previous section. For the OpCo's using DR, LSP supplies both the carstocks and QRS’s directly out of the RSC. There are three concepts of DR, depending on the type of ownership of the stock;

- DR1; In this case, LSP ‘sells’ the service parts to the OpCo, and therefore LSP does not have direct insight in the inventory of the fieldstock locations. DR1-countries are Ireland, United Kingdom, Portugal, Spain, France, Belgium and Italy.
- DR2; For DR2, LSP owns the service parts in the QRS’s, and sells the parts to the OpCo’s when the part is delivered to the carstock. DR2-countries are Norway, Sweden, Finland and Denmark.
- DR3; In the DR3-concept, LSP owns the service parts in the entire service parts supply chain until the part is sold or booked to the final customer. At this moment, the DR3-concept is active in the Netherlands, Germany, Switzerland and Austria.

About four years ago, the DR3-concept was developed in order to improve visibility in the supply chain. The DR3-concept is part of the Océ-project ‘Centrally Managed Logistics’. The goal of this company-wide project is to reduce logistical costs by improving visibility in all relevant supply chains. Therefore, it is planned to introduce the DR3-concept in all high revenue OpCo’s within a few years.

To improve the visibility in the service parts supply chain, LSP is now accountable for the fieldstocks of the DR3-OpCo’s. However, the second step in the DR3-development, a centrally managed logistical process, is under development. For this development, among other actions, a fieldstock inventory model needs to be developed. The development of this model was the reason to initiate this graduation project.

2. Problem description

In the previous chapter, the context of the project was discussed. This chapter describes the problem cluster and main subject of the graduation project. This is the first step in the regulative cycle of Van Strien. Therefore, in Section 2.1 a description is given about the problems related to the context described in the previous chapter. This description results in the research assignment, which is stated in Section 2.2. Finally, Section 2.3 describes the scope of the project.

2.1. Problem cluster

As was stated in the previous chapter, the initial goal of the project was to develop a method that makes it possible to manage the fieldstock efficiently. To explore the background of this initial project description and the problems related to the current situation, interviews were conducted with stakeholders related to the service parts supply chain. The outcomes of the interviews are shown in the problem cluster displayed in Figure 4. The problem cluster is used as starting point for the analysis phase. The rest of this section describes the problem cluster and the main focus of the analysis phase.

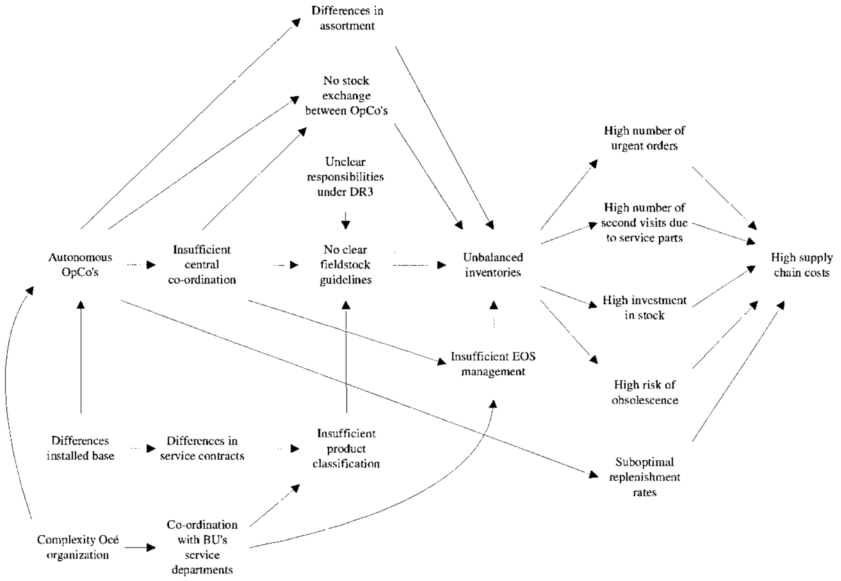


Figure 4; problem cluster

After the interviews with the main stakeholders, it can be concluded that they have the opinion that the main problem for the service parts supply chain is the high total costs with regard to the current service levels. The high supply chain costs may be caused by an unbalanced inventory of service parts within the fieldstock. This unbalanced inventory can be seen at two aspects of the supply chain. The first aspect is an unbalanced inventory with regard to service parts. This means that some parts have excessive stock, whereas other service parts have insufficient stock. The second aspect of the unbalanced inventory is the location aspect. This means that some stocking points in the supply chain have excessive stock, whereas other stocking points have insufficient stock.

According to the stakeholders, the main cause for these unbalanced inventories is a product flow that is insufficiently centrally co-ordinated, without the use of clear fieldstock guidelines. The OpCo's control the fieldstock, and their primary goal is a high customer satisfaction and thus not necessarily a minimal cost level. On the one hand this results in a good adjustment to the actual needs of the customers in a country, but on the other hand this may lead to inefficiencies in the service parts supply chain. The unbalanced inventory may have the following consequences for Océ:

- A high investment in inventory, not resulting in a service level that is optimal regarding this investment.
- A relatively high number of urgent orders. These urgent orders are more expensive than regular orders.
- High risk of obsolescence of the inventory.
- A high number of second visits of technicians due to a lack of service parts. This results in higher costs and lower customer satisfaction.

Besides the uncoordinated product flow, the stakeholders mention some other possible causes for the high service parts supply chain costs:

- Within the Océ organisation, the OpCo's are relatively autonomous. This leads to a couple of difficulties for the service part supply chain;
    - The difference in assortment between OpCo's is significant. This is partly due to differences in installed base, and partly due to differences in service organisations between OpCo's.
    - There is no communication between OpCo's in neighbouring countries, which may be the reason for unnecessary transportation and inefficient use of fieldstock near the border.
    - Some OpCo's store a significant amount of local assortment. This local assortment is not supported by Océ HQ, which may result in inefficient buying decisions. Furthermore, the same local assortment may be stocked at different OpCo's.
- Life cycle management of service parts is not always sufficient. Especially towards the end of the product life cycle it seems that parts are ordered in large quantities, whereas this is not necessary. Furthermore, the End Of Service (EOS)-date is sometimes postponed, resulting in difficulties for stock control.
- At this moment, the DR3-OpCo's co-ordinate the product flow, whereas LSP is accountable. Without the financial responsibilities, the OpCo's are not triggered to make their supply chain more efficient. Their main target is a high customer satisfaction, and they do not need to take supply chain costs into account.
- The classification of service parts is not sufficient, meaning that it is not really known how critical the different service parts are for customers. The criticality has influence on the required response times, and thus on the inventory control.

2.2. Research assignment

In the previous section, a description is given about the main focus of the project, based on the problem cluster in Figure 4. This section defines the research assignment that will be used to analyse the problems stated in the previous section. Therefore, the following research assignment is formulated:

Analyse whether the fieldstock inventory of service parts of Océ is unbalanced and whether this is caused by unclear fieldstock guidelines or by other factors mentioned in the problem cluster.

Related to the problem cluster in Figure 4, this research assignment enables an analysis of the relation between 'no clear fieldstock guidelines' and 'unbalanced inventories'. This means that the first goal is to find out whether the inventory is unbalanced. If the analysis reveals that the inventory is unbalanced, the main cause for this unbalanced inventory needs to be found. According to the stakeholders, an important cause is the 'unclear fieldstock guidelines', and therefore, the analysis focuses on this aspect. However, the other three possible causes for an unbalanced inventory are also analysed in order to find out what the influence of these causes is.

This means that two analyses are executed; an inventory analysis, and an analysis of the inventory management at the OpCo's. Subsection 2.2.1 introduces the inventory analysis, and Subsection 2.2.2 describes how the analysis of the inventory management is executed.

2.2.1. Unbalanced inventory

This subsection gives a description of the first half of the problem cluster; an analysis of the unbalanced fieldstock inventory. This is described in order to execute the research assignment described in Section 2.2.

In general, the fieldstock inventory has to guarantee that technicians are able to repair machines at the customers. To keep customers satisfied and meet service requirements, certain service levels need to be met. For the service parts supply chain, the second visit rate due to a lack of service parts is the most important service performance indicator. Other performance indicators are not directly linked to the availability of service parts, and depend on other issues, such as planning of technician capacity and skills of the technicians.

The second visit rate due to parts should be achieved as efficient as possible, which means that the inventory must be well managed with regard to location and products. In general, there are two dominant factors that determine whether inventory is balanced, or well managed (see for example Botter & Fortuin (2000)):

1. The demand for service parts. Service parts with a high demand need to be stored close to the customer, in order to prevent unnecessary transportation of these service parts, whereas service parts with a low demand need to be stored on a more central location.
2. The value of a service part. Expensive service parts should be stored in a location that can be used by multiple technicians. This avoids the storage of these service parts in multiple locations, and thus saves storage costs. Cheaper service parts can be stored in a location closer to the final customer, because the total inventory value of these service parts will be low compared to the total value of the inventory.

For Océ, this results in a situation for the positioning of service parts in the service parts supply chain, as shown in Figure 5. On the horizontal axis, the demand for the service part is shown, and on the vertical axis the value of the service part.

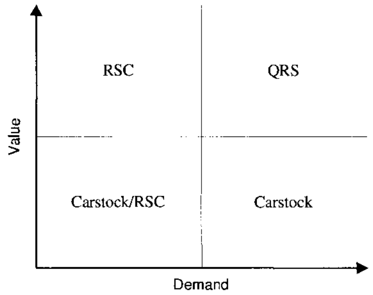


Figure 5; positioning of service parts at Océ

Figure 5 shows that service parts that have a low demand and a high value should be stored at a central location, which in the case of Océ is the RSC. For the service parts with a low demand and low value there are two possible locations to store service parts. If the demand is very low, the RSC is the best location to store the part, but if the demand is somewhat higher, it is no problem to store it in the carstock. High value, high demand service parts can best be stored in a more central location, but still close to the final customer, which means storing these parts in the QRS. It is important to manage the quantity of these parts, in order to prevent excessive stock of these high-value parts. High demand, low value service parts can best be stored in the carstock. For these parts, a somewhat higher stock level is acceptable, because the value of these parts is relatively low.

This inventory strategy also has consequences for the other characteristics of the fieldstock:

- Because certain service parts are stored in the RSC, and not in the fieldstock, it is more justified to order them urgently than for other service parts. The urgent order analysis can be found in Section 3.2.
- For parts that cause second visits, the same is true as for the urgent orders. This means that for service parts stored in the RSC, more second visits may be the result, because this is cheaper than storing them in the fieldstock. This analysis is described in Section 3.3.
- The investment in fieldstock, which means that it is analysed whether the investment in the fieldstock is in accordance to Figure 5. The investment in fieldstock is analysed in Section 3.4.
- Service parts that have a higher risk of obsolescence should be stored in a more central location of the supply chain. This prevents unnecessary storage costs for parts becoming obsolete in lower-echelon locations of the supply chain. This analysis can be found in Section 3.5.

2.2.2. Fieldstock management

This subsection describes the second part of the problem cluster; the possible causes of an unbalanced inventory. As said before, there are four possible causes for the unbalanced fieldstock inventory at Océ; differences in assortment between the OpCo's, no stock exchange between the OpCo's, unclear fieldstock guidelines, and insufficient EOS-management.

Differences in assortment

As mentioned by the stakeholders, differences in assortment between OpCo's may be the cause of an unbalanced inventory. This is due to the fact that it may not be possible to control the fieldstock in a central way, because of differences between the assortments of the OpCo's. These differences do not only depend on the installed base, but also depend on the demand for service parts. To analyse this, the installed base per OpCo is analysed, and the demand for service parts per OpCo is analysed. The entire analysis is described in Section 4.2.

Stock exchange between OpCo's

Another possible cause for an unbalanced inventory is the lack of stock exchange between OpCo's. Because no stock exchange between OpCo's takes place, the inventory may not be used in an efficient way. This may be the case if two fieldstock locations close to the border are not managed together. This analysis can be found in Section 4.3.

Fieldstock guidelines
Certain rules and guidelines are used by the OpCo's to control the fieldstock of service parts. This includes rules and guidelines about assortment, reorder levels, responsibilities, etcetera. These guidelines need to make sure that the fieldstock is controlled in such a way that the service requirements are met, and preferably as efficient as possible. These guidelines might be explicit in the form of models, but also implicit in the inventory management of the technicians and Field Service Managers (FSM's). This analysis is described in Section 0.

EOS-management
The fourth possible cause for an unbalanced inventory is insufficient EOS-management. This means that service parts are not managed well with regard to the life cycle of the parts. This is analysed by describing the current methods of EOS-management in Section 4.5.

2.3. Project scope

The previous sections describe the research assignment, and the analyses that need to be made to execute the research assignment. This section describes the scope of these analyses. Therefore, in Subsection 2.3.1, a selection is made of OpCo's that are analysed. Subsection 2.3.2 defines the service parts that are analysed.

2.3.1. OpCo Selection

Due to time restrictions, it is not possible to analyse all DR-OpCo's. Therefore, four OpCo's had to be selected, which had to give a representative overview of all OpCo's. To select these OpCo's, three characteristics were defined:

1. The size of a country and the size of the OpCo; the logistical parameters of an OpCo partly depend on the density of the installed base of a country. For example, a large installed base in a small country makes it possible for technicians to specialise, and their productivity may be higher, due to smaller travelling times compared to less dense countries.
2. Actual performance of OpCo's; the differences in performance between OpCo's may be caused by the guidelines an OpCo uses to control its fieldstock. For the OpCo selection, the percentage of urgent orders and the second visit rate are selected as performance indicators. In order to find the causes for these differences, it is interesting to investigate OpCo's with different performance levels.
3. Willingness to co-operate. If an OpCo is willing to co-operate, it is easier to gather data from that OpCo. To analyse the willingness to co-operate, a small questionnaire was sent to the OpCo's, in which the OpCo's were asked to indicate if they use the current carstock model, and if not, which other criteria they use to control their fieldstock. Furthermore, the department of CS&S was asked to give information about the willingness to co-operate.

All DR-OpCo's were compared by using these three characteristics. The comparison results in the selection of the following four OpCo's:

- Germany; OpCo Germany is the best performing OpCo compared to the other OpCo's. This makes it interesting to find out why this OpCo performs well. Furthermore, Germany is one of the largest OpCo's, and DR3 is fully implemented in Germany, which makes it easier to gather data.
- Belgium; OpCo Belgium is selected, because Belgium is willing to co-operate with LSP to develop a new fieldstock model. Belgium has a large revenue compared to its size, and has an average performance compared to other OpCo's.
- Spain; OpCo Spain is selected because it is a high revenue OpCo, but the installed base is spread out over a relatively large area. Thereby, it is an average performing OpCo compared to the other OpCo's. Furthermore, they are willing to co-operate with the project.
- Norway; OpCo Norway is selected because it is a lower-revenue OpCo than the other OpCo's. The performance of Norway is average compared to the other OpCo's.

2.3.2. Product classification

Because the problem description is based on the service parts controlled by LSP, the scope of the project is limited to these service parts. This subsection defines these service parts.

The classification of service parts offered by Océ is based on the machine a part belongs to. Besides machines produced by Océ, OpCo's often sell and service machines that are produced by other manufacturers. However, Océ HQ does not always support the service parts for these machines. The service parts that are not supported by the Océ HQ are also called 'local assortment'. The OpCo's buy these service parts from other parties.

All service parts belonging to machines supported by Océ HQ are part of the 'corporate assortment'. This assortment is divided in the two business units; WFPS and DDS. The business unit WFPS is split up into two profit centres: Display Graphics (DG) and Technical Document Systems (TDS). The continuous feed machines, belonging to the business unit DDS, are produced in Poing (Germany). The service parts supply chain for these continuous feed machines is separated from the service parts supply chain of the other machines. Therefore, these machines are not taken into account for this project. The service parts within the scope of the project are shown in the rectangle in the left part of Figure 6.

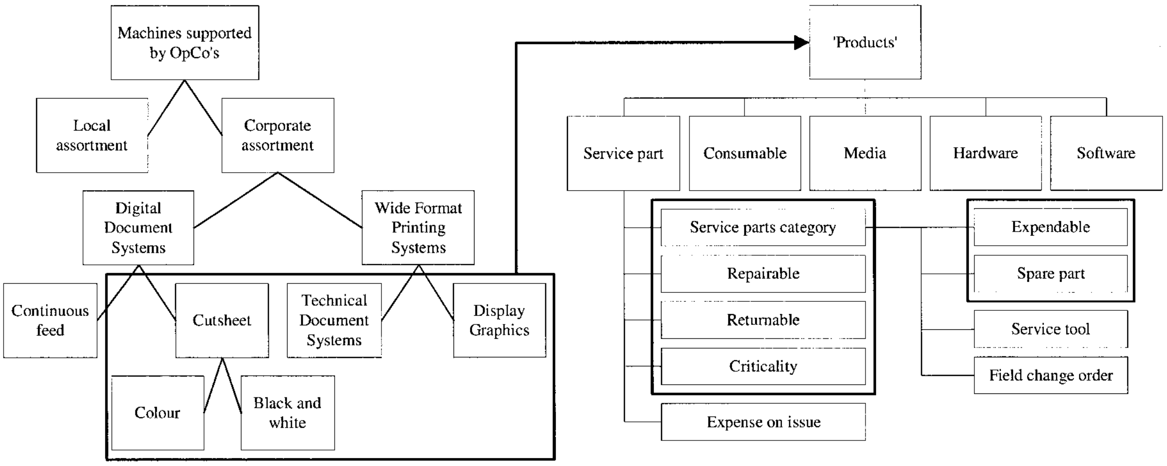


Figure 6; overview of the Océ machines, and scope of the project

For the machines within the scope of this project, all items that have a unique registered code number are defined as 'products'. The business units take the decisions about the product classification. When a new machine is introduced, the service departments determine which parts of the machine belong to which type of product. The right part of Figure 6 shows the product classification as defined by the business units. It shows the five different types of products. Each product belonging to the category 'service part' can has one or more of the attributes shown in the lower part of the figure. Definitions of the products and the attributes can be found in Appendix B.

The focus of this project is on the service parts within the rectangles of Figure 6. These are the service parts that are managed by LSP. Service parts with the attributes 'Expense on issue (EOI)' and 'service tool' are excluded for the project. EOI-parts are not administrated in the fieldstock and not linked to a certain machine, and thus not measurable as a sale. The value of these parts is usually limited. The 'field change order' service parts are also excluded for this research, because these parts are one-time events, and therefore do not need to be stored in the fieldstock.

Most service parts controlled by LSP are replaced when the part breaks down. This means that these parts only have corrective maintenance. However, for some other service parts, preventive maintenance takes place. If a customer phones the OpCo because the machine does not meet the customer's requirements, the technician travels to that machine, and tries to solve this. The technician will also check certain parameters of the machine. These parameters include data about the number of copies and condition of certain parts. If these parameters exceed certain values, the technician will execute preventive maintenance on specific parts in the machine, and perhaps replace these parts. In general, a technician does not know whether he will execute preventive maintenance before he arrives at the machine. Therefore, it can be said, that these repairs are preventive from a technical point of view, but from a logistical point of view, these repairs are not planned on beforehand, and thus corrective.

3. Inventory analysis

This chapter describes the first half of the analysis; the inventory analysis. The goal of the chapter is to find out whether the fieldstock inventory is unbalanced with regard to the required service levels. Figure 7 shows the problem cluster with regard to the consequences of an unbalanced inventory, and the corresponding sections. The service levels of the RSC influence the fieldstock inventory and therefore these service levels are described in Section 3.1. The conclusions of this chapter can be found in Section 3.6.

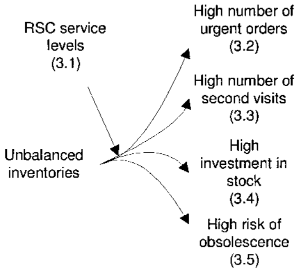


Figure 7; inventory analysis

3.1. RSC Service levels

For all non-DR3 OpCo's, performance reports are produced each month. For the DR3-OpCo's, a performance measurement system is currently being developed, and therefore no recent performance data for Germany are available. However, there is no reason to assume that the service levels for OpCo Germany are different than the service levels for other OpCo's. For the OpCo's Belgium, Spain and Norway, the performance of the RSC from June 2006 to May 2007 can be found in Table 1. This table shows the percentage of orderlines that was delivered complete and on time in the truck of the logistics service provider. The logistics service provider transports the service parts to the OpCo's. The target for the regular orders is to deliver 98% of the orderlines complete and on time. For the urgent orders, the target is set at 99%.

OpCo	Regular (target = 98%)	Urgent (target = 99%)
Belgium	99,0%	97,6%
Spain	99,1%	97,9%
Norway	98,0%	97,9%

Table 1; overview of the delivery performance of the RSC

The target of 98% for regular orders has been met for all three OpCo's in the selected period. The target for the urgent orders was not met in the entire period. It is relatively easy to meet the target for the regular orders, because this includes fast-moving service parts. The urgent orders often contain (very) slow moving and expensive parts, which are stored in smaller quantities. In the future, the delivery performance may be specified for specific categories of service parts, based on machine type and criticality.

3.2. Urgent orders

In this section, the percentage of urgent orders placed at the RSC is analysed. As said before, the percentage of urgent orders is an indicator for the availability of service parts, because a missing service part may result in an urgent order. OpCo's Norway and Spain indicate that their percentage of urgent orders may be higher because the replenishment lead times for these OpCo's are longer than for OpCo's that are closer to the RSC. This makes it sometimes necessary to urgently order a service part to meet customer demand. The replenishment lead times for the selected OpCo's can be found in Appendix C.

In Subsections 3.2.1 and 3.2.2 the characteristics of the urgently ordered service parts are described. For these subsections, it is decided to select only those service parts that have been urgently ordered for more than 40% of the orders for that part. If the urgent order percentage is below 40%, this part is considered as a part with a low percentage of urgent orders. Including these service parts would result in an analysis with many service parts with a small percentage of urgent orders, for which it is not realistic to mark them as an 'urgently ordered service part'.

3.2.1. Characteristics of urgently ordered parts

This subsection analyses the total demand for urgently ordered parts and the value of the urgently ordered service parts. As said before, for high-value service parts, it is more economically justified to order them urgently than for low-value service parts. For high-value service parts the costs of an urgent order may outweigh the costs of storing them in the fieldstock. Therefore, in Figure 8, an overview is given of the value and total demand of the urgently ordered service parts.

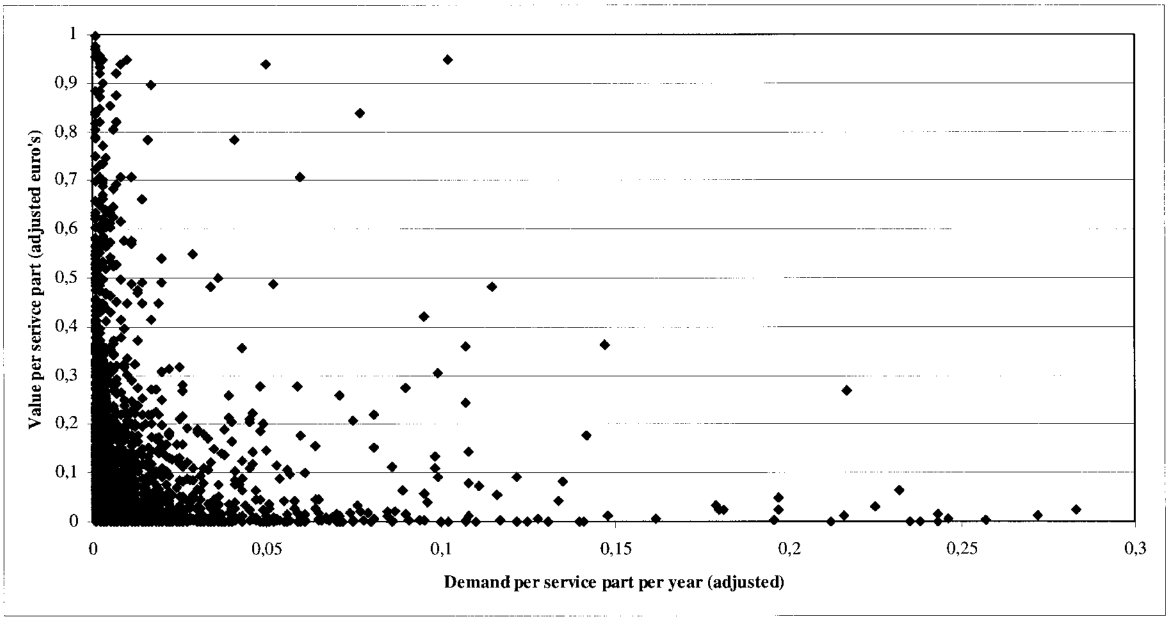


Figure 8; overview of the characteristics of urgently ordered parts

As can be seen in Figure 8, most of the urgently ordered parts have a relatively low demand. With regard to the inventory strategy this seems to be the right strategy, as for the high value service parts, it is more economically justified to order them urgently. However, a significant amount of the urgently ordered parts have a low value. For example, 74% of the urgently ordered service parts have a value lower than € 50. It is questionable whether these service parts need to be urgently ordered. Perhaps it is better to store these service parts in the fieldstock, and thus avoiding urgent orders for these parts.

3.2.2. Urgently ordered parts in the fieldstock

The previous subsection shows the characteristics of the urgently ordered service parts. However, it is also required to analyse whether these urgently ordered service parts are stored in the fieldstock of the OpCo's. Thereby, the following two types of urgently ordered service parts may indicate that the fieldstock inventory is unbalanced:

1. Service parts that are stored in the fieldstock, but still urgently ordered often. These service parts may be stored at wrong locations in the supply chain, or in insufficient quantities. For the selected OpCo's, 72% of the urgently ordered parts are not stored in the fieldstock. The 28% of the service parts that are stored in the fieldstock are stored in small quantities. Therefore, it can be concluded that most urgently ordered service parts are not stored in the fieldstock in large quantities.
2. Service parts that are urgently ordered frequently, whereas these service parts are not stored in the fieldstock. These parts should be stored in the fieldstock, to avoid urgent orders. In total, 88% of the urgently ordered parts per OpCo were ordered between 1 and 5 times per year. This means that it seems that there is no need to store these parts in the fieldstock.

3.2.3. Conclusions about urgent orders

The analyses in Subsections 3.2.1 and 3.2.2 lead to the conclusion that the inventory strategy with regard to urgent orders seems to be the correct strategy. This means that most urgently ordered service parts have a relatively high value and low demand. These service parts can best be stored at the RSC, and ordered urgently if needed. Furthermore, service parts stored in the fieldstock are not urgently ordered frequently, and service parts that are not stored in the fieldstock are not urgently ordered in large quantities either. It seems that the OpCo's manage the fieldstock inventory well with regard to the urgent orders. However, care needs to be taken with the low value service parts, which still represent a large portion of the urgent orders.

3.3. Second visits due to service parts

In this section, the number of second visits due to service parts is analysed. As said before, the second visit rate is an important performance indicator for Océ. The goal of this section is to analyse whether the percentage of second visits meets the required service levels, and whether the second visits may be caused by an unbalanced inventory.

Within Océ, three types of second visits are defined;

1. Second visits due to skills. If a technician cannot repair a machine because he has insufficient knowledge about the machine, and another technician needs to repair the machine, this results in a second visit due to skills.
2. Second visits due to time. If a technician is repairing a machine, and the customer ends its working day, or the technician ends his working day, the technician has to come back for a second visit due to time.
3. Second visit due to parts. If a technician has to return to the same customer, because he does not have the right parts available, this leads to a second visit due to parts. This section focuses on this category.

There are two types of service parts that cause second visits and indicate an unbalanced inventory;

1. Service parts with a second visit rate above target, which are stored in the fieldstock in significant quantities. This means that the service parts are stored in the fieldstock, but still generate second visits.
2. Service parts with a second visit rate above target that are not stored in the fieldstock. These service parts should be stored in the fieldstock, in order to avoid unnecessary second visits. However, this is only the case for service parts that generate a relatively large quantity of second visits.

To execute this analysis, all service parts that caused a second visit in the analysis period were selected. 50% of these selected parts caused just one second visit. Only 8% of the selected service parts caused more than five second visits. Because of the low amount of these service parts, and the differences in storage of these parts, no significant conclusions can be based on this analysis.

In general, it can be said that most service parts only cause a few second visits. The service parts that cause more second visits are not stored in sufficient quantities or these service parts are stored at the wrong location. However, no specific target is set for the second visits due to service parts, and therefore it is difficult to evaluate the OpCo's with regard to this performance indicator.

3.4. Investment in fieldstock inventory

This section describes the analysis of the fieldstock with regard to the investment in inventory. One of the results of an unbalanced inventory could be a high investment in stock with regard to the required service levels. Therefore, Subsection 3.4.1 contains an analysis of the investment in QRS stocks, followed by an analysis of the investment in carstocks in Subsection 3.4.2, and an analysis of the total fieldstock inventory per service part in Subsection 3.4.3.

3.4.1. Investment in QRS inventory

In this section the inventory in the QRS's is analysed. The goal is to find out whether the investment in QRS inventory is unbalanced. OpCo Belgium is excluded from this analysis because this OpCo does not have QRS's. To give an overview of investment in QRS inventories, Figure 9 shows the characteristics of the service parts that are stored in the QRS's. This is an overview of all QRS's in the three OpCo's combined.

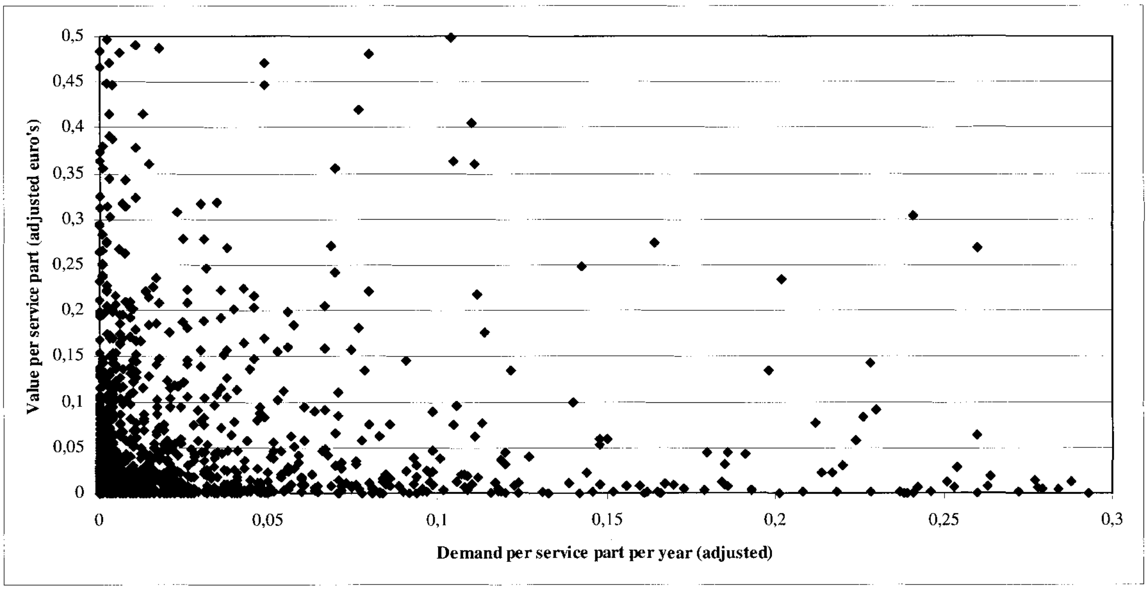


Figure 9; overview of the service parts stored in the QRS's at the three OpCo's

Figure 9 shows that the total demand for service parts stored in the QRS varies between (very) low and relatively high. As said before, it is questionable whether service parts with a (very) low, or high demand should be stored in the QRS. Furthermore, a significant amount of service parts with a low value is stored in the QRS's. No strategy seems to be in use for the inventory management at the QRS's.

Concluding, it can be said that the QRS inventories contain a significant amount of service parts with a low value. Although the total inventory costs for these parts will be limited, the transportation costs from the QRS to the customer may outweigh the costs of keeping these service parts in the carstocks, especially for the service parts with a higher demand. The high-value service parts should be stored in the QRS.

3.4.2. Investment in carstock inventory

In this section, the investment in service parts for the carstocks is analysed. This analysis can be related to the results of the QRS analysis in the previous section, in order to compare the carstocks with the QRS's. To execute the carstock analysis, Figure 10 contains an overview of parts identified as carstock parts, with regard to their value and total demand. Service parts that are stored in a low quantity in the OpCo are excluded, because a service part that is only stored in a couple of carstocks, hardly contributes to the service level. For OpCo Germany, all service parts stored in a quantity smaller than five items were removed, for Belgium and Spain all parts with less than three items in stock were removed, and for Norway all service parts with a carstock quantity of one or two were removed. These values are based on the total number of carstocks per OpCo.

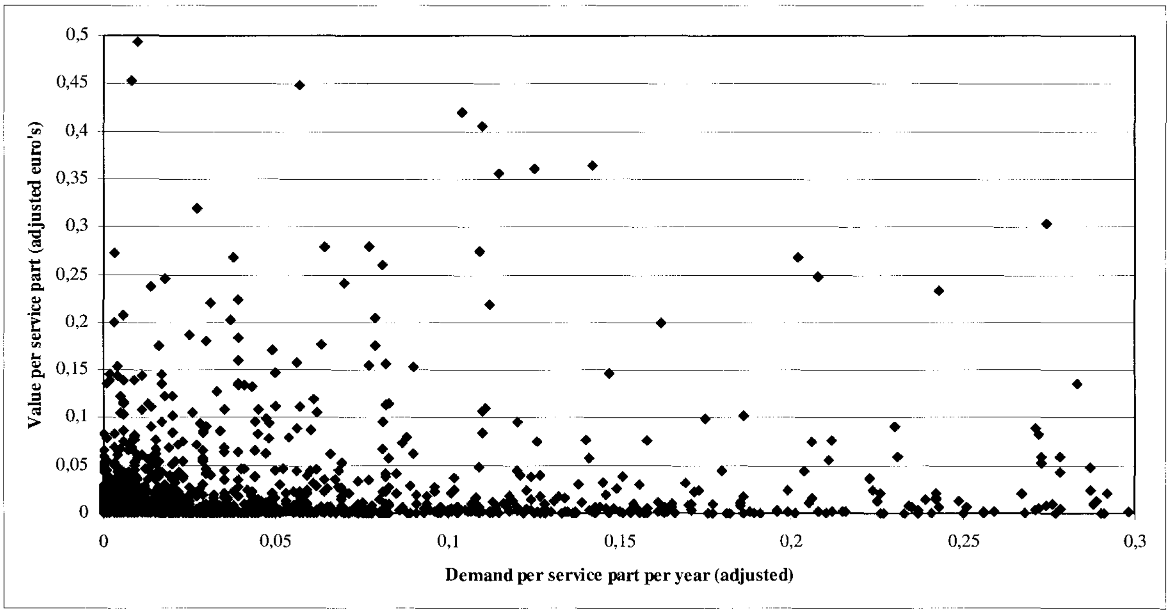


Figure 10; characteristics of the service parts stored in the carstocks

As can be seen in Figure 10, the demand for carstock parts is relatively high compared to the demand for QRS parts, which can be found in Figure 9. This means that the carstocks are used to store service parts with a high demand. However, the high value service parts represent a significant amount of the total carstock value. These parts should be managed with care, and perhaps the QRS is a better location to store these service parts.

Concluding, it can be said that the carstocks mostly contain low value service parts with a relatively high demand. However, the high value parts determine a significant percentage of the total value of the carstocks. Therefore, these parts should be managed carefully, and if demand is low, the QRS is a better place to store these parts.

3.4.3. Fieldstock inventory per service part

With regard to the investment per service part, the demand for a service part needs to be compared with the total fieldstock inventory of that service part. This makes it possible to calculate the inventory position per service part. The inventory position is defined as the time period that is required to sell all parts that are currently stored in the fieldstock. To analyse this, Figure 11 gives an overview of the inventory position per service part.

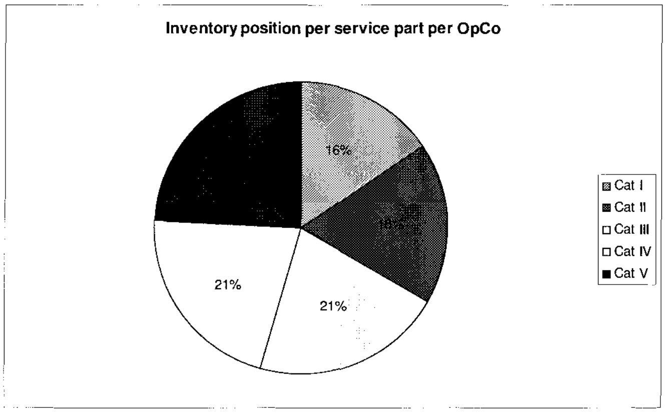


Figure 11; overview of the inventory position per service part (adjusted in categories)

As can be seen in Figure 11, there are significant differences in inventory position between different service parts. Furthermore, a significant amount of the service parts have a high inventory position; 21% of the service parts have an inventory position equal to category IV, and 24% of the service part has an inventory position equal to category V. The value of the service parts in categories IV and V is relatively small. This means that the faster moving service parts represent most of the fieldstock value.

As a conclusion it can be said that the total investment in fieldstock inventory with regard to the inventory position is unbalanced; some service parts have a high inventory with regard to the demand, whereas other parts have a low inventory compared to the demand. Furthermore, a large amount of the service parts generated low demand. This leads to a relatively large and unbalanced investment in service parts.

3.5. Risk of obsolescence

This section describes the risk of obsolescence of the service parts stored in the fieldstock. This was identified as one of the possible consequences of an unbalanced inventory.

In general, there are two reasons for a service part becoming obsolete:

1. The demand for a service part decreases, whereas the inventory of this service part is on a higher level than expected for this decreasing demand. For service parts with an EOS-date that is close to the current date, this risk is greater than for service parts with an EOS-date further away.
2. Due to a technical change of a machine, a service part may not be needed anymore, whereas this part is still stored in the supply chain. This also results in an obsolete service part.

The first reason for obsolescence depends on supply chain management, whereas the second reason depends on other factors, such as technical aspects of machines and service parts. Therefore, the focus of this analysis is the risk of obsolescence due to a nearing EOS-date. To manage parts with regard to their EOS, all service parts have the attribute 'end of service'. This attribute is a year varying from 2005 to 2015 and represents the final year that the service part will be supported by Océ HQ. However, because some service parts are used in multiple machines, the EOS-date of a service part is equal to the EOS-date of the machine that generates most of the demand for that service part. This means that not all the parts with an EOS-date in the near future are really becoming obsolete, because these service parts may still be used in other machines. The majority of the service parts stored in the fieldstock have an EOS-date that is further away than 2008. The risk of obsolescence for these parts is quite small, because demand for these service parts will be sufficient to keep this inventory moving.

It can be said that the fieldstock of the OpCo's contains a significant amount of service parts for which the EOS-date requires careful management. Especially the service parts with an EOS-date in the past represent a high risk of obsolescence. However, the total value of these parts is relatively small.

3.6. Conclusions

This section contains the main conclusions of this chapter. The goal of this chapter is to answer the question whether the fieldstock inventory is unbalanced. This is done by analysing the following characteristics of the service parts in the fieldstock; urgently ordered service parts, second visits due to parts, investment in service parts and the EOS-date of service parts.

With regard to the unbalance of the fieldstock inventory it can be said that the total investment in inventory seems to be unbalanced with regard to the required service levels. This is based on the following analyses:

- If the fieldstock inventory per service part is compared with the demand for that service part, significant differences in inventory per service part can be seen. Some service parts have an inventory that represents less than three months of demand, whereas other service parts have an inventory that represents more than one year of demand. A significant percentage of the service parts did not generate any demand during the analysis period.
- In the QRS's, low-demand parts as well as high-demand service parts are stored, and the value of these parts varies significantly. This results in a relatively high investment in stock for the QRS's for the wrong service parts.
- The carstock mostly contains low-value service parts. However, the high-value service parts represent a significant portion of the total carstock value, resulting in a high investment in carstock inventory. Some of these high-value service parts should be stored in a QRS.

The influence of the other possible causes on the unbalanced inventory seems to be limited. With regard to the urgent orders, the main conclusion is that there are no service parts urgently ordered in large quantities. This includes service parts stored in the fieldstock as well as service parts that are not stored in the fieldstock. For the service parts causing a second visit it can be concluded that most service parts only cause a few second visits. The total risk of obsolescence is limited, although there is a significant amount of service parts with an EOS-date in the past or nearby. These service parts only represent a small percentage of the total fieldstock value, and therefore the total risk of obsolescence is limited.

4. Analysis of fieldstock management

In the previous chapter it was concluded that the total investment in service parts seems to be unbalanced with regard to the required service levels. This chapter analyses the possible causes for this unbalanced inventory. Figure 12 shows the analyses that are executed, and the corresponding sections. This chapter starts with a description of the order handling process from the RSC to the OpCo's, because this influences the fieldstock management within an OpCo. The chapter ends with a conclusion in Section 4.6.

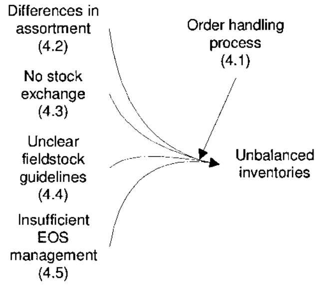


Figure 12; analysis of fieldstock management

4.1. Order handling process

The order handling process as described in this section describes the process from the moment an item is being ordered at the RSC until it is delivered at the fieldstock location. This process influences the fieldstock inventory, because a certain replenishment lead-time needs to be taken into account for the fieldstock management.

If a service part is used by a technician or ordered at the RSC, this order is automatically registered at LSP. LSP makes sure that this service part will be replenished as soon as the next replenishment for that specific OpCo is scheduled. When a replenishment is scheduled, all orders are picked in the RSC, and all items are sorted per fieldstock location, and placed in a box. At a specific cut-off time, a logistics service provider picks the boxes at the RSC, and delivers them to the technicians and QRS's. The cut-off time is the latest moment in time that an OpCo can order a service part at the RSC. This cut-off time is different per OpCo, and depends on the logistics service provider and on the transportation time to the OpCo. Table 2 contains an overview of the replenishment rate and lead-time per OpCo. The lead-time is the time between the cut-off time and the time that the technician receives the replenishment. A more detailed description of the time schedules can be found in Appendix C.

OpCo	Replenishments per week	Lead-time (working days)
Germany	5	1
Belgium	5	1
Spain	3	3 - 4
Norway	2	4 - 5

Table 2; overview of the characteristics of regular orders per OpCo

Urgent orders are picked on the same day as they are ordered, before a specific cut-off time. The logistics service provider makes sure that the order is delivered to the technician the next day, before a particular time. This results in a lead-time for the urgent orders that is smaller than 24 hours for most technicians. An overview of the different types of order handling per OpCo and the time schedule can be found in Appendix C.

4.2. Differences in assortment

This section describes the differences in assortment between the selected OpCo's. Large differences in assortment may limit the possibility to introduce a generic fieldstock model. The differences in assortment can be seen at two characteristics of the OpCo's:

1. Differences in installed base; this may result in different required service levels, and different service management for this installed base. Because the scope of this analysis is Océ's corporate assortment, the consequences of differences in the installed base are limited. The local assortment is the OpCo's responsibility.
2. Differences in demand for service parts. This may be the result of different maintenance strategies, for example with regard to the use of service parts by technicians. If there are differences in the demand for service parts, this may require a different inventory strategy. The analysis reveals that there are significant differences between the OpCo's. This has no consequences for the fieldstock management

within one OpCo, but for the inventory management at the RSC this results in a relatively large investment in slow-moving service parts. Furthermore, it shows that no corporate policy is used with regard to the assortment of service parts.

As a conclusion it can be said that, although there are differences in assortment between the OpCo's, these differences do not influence the fieldstock management within one OpCo. This has consequences for the inventory management at the RSC. It may lead to a large amount of slow moving service parts that need to be stocked, or a lower availability of these parts, because it is harder to manage these parts.

4.3. Stock exchange between OpCo's

In this section, the possibilities of stock exchange between OpCo's are described. Stock exchange between OpCo's may result in more efficient inventory management.

In the current situation, it is possible to exchange stock between all fieldstock inventories owned by LSP. This means that there is the possibility to exchange stock between all fieldstock locations of the DR3-OpCo's, and the QRS stocks of the DR2-countries. LSP may initiate a stock transfer if one OpCo has service parts on stock and another OpCo needs these parts. However, this does not influence the fieldstock management within one OpCo, and is therefore not within the scope of this analysis.

In the future, it is also possible to exchange stock between fieldstock locations on a more operational basis for DR3-OpCo's. This means that if a technician does not have the required part in a fieldstock location nearby, the part may be supplied by a fieldstock location of a nearby OpCo. Because of time restrictions, this will only be useful for technicians working close to the border. The information systems do not support these cross-border deliveries yet.

Cross-border stock exchange is less interesting for low-density countries like Spain and Norway. These OpCo's indicate that currently lateral transhipment between QRS's within their OpCo only takes place in exceptional cases. This is due to the relatively long transportation time between fieldstock locations in these countries compared to the lead-time of an urgent order from the RSC. For OpCo's it is often faster or just as fast to urgently order a service part at the RSC than a lateral transhipment between fieldstock locations.

It can be concluded that operational cross-border deliveries may result in a more balanced fieldstock inventory, but that due to transportation times, this is only relevant for high-density areas near the border.

4.4. Fieldstock inventory guidelines

This section describes the guidelines used by the OpCo's to manage the fieldstock inventories. Because some OpCo's use a model to control the carstock, this carstock model is explained in Subsection 4.4.1. Subsection 4.4.2 contains a description of the guidelines the OpCo's use to manage their fieldstock.

4.4.1. Carstock model

In the 1990s, Océ developed the carstock model, in order to give the OpCo's a tool that can be used to generate advices for the carstock inventory. It was developed as an add-on for the information system OCS. The OpCo's use this information system to manage carstock inventories, demand for service parts, etcetera.

The carstock model applies a single-item approach. For each service part, the carstock model compares two cost factors. First, the total expected costs of second visits for one year are calculated if the part is not kept on stock. Second, the costs of storing one item during one year are calculated. If the second visit costs outweigh the storage costs, it is economically justified to store the service part in the carstock. Besides these calculations, two minimum usage levels are used to adjust the advice. These minimum usage levels represent a minimum required usage per year, and limit the number of items that have to be stored in the carstock. In total, this results in five categories of service parts:

1. Strongly advised parts; It is economically justified to store these parts in the carstock, and the expected usage is larger than the first minimum usage level. Most OpCo's use a minimum usage level of 4.
2. Advised parts; For these parts, it is also economically justified to store them in the carstock. The expected usage is larger than the second minimum usage level. Most OpCo's use a minimum usage level of 1.
3. Not advised, but economical justified parts. For these parts it is economically justified to store them in the carstock, but their expected usage is too low. The advised basestock level for these parts is 0.
4. Pre-advised parts. These are the parts marked by the service department as service parts that need to be in a carstock, but these parts do not belong to categories 1 or 2.

5. Not advised parts, but currently identified as carstock parts. These are category 3 parts, but the decision was made to keep these parts in the carstock.

There are two major drawbacks with regard to the carstock model. For most service parts, the costs of a second visit are almost always larger than the costs of inventory keeping. This means that it is economically justified to store most service parts in the carstock, and that the usage restrictions have a large influence on the model. This results in the situation that the model classifies and stores service parts based on the expected usage of single service parts. Therefore it is not known whether the advice minimises the total costs with regard to a target service level. Another drawback is that an estimation needs to be made about the costs of a second visit. It is difficult to determine which cost factors belong to these costs, and therefore it is hard to make a good estimation. A more detailed and mathematical description of the carstock model can be found in Appendix D.

4.4.2. Fieldstock guidelines

This subsection describes the guidelines that are used by the selected OpCo's to manage the fieldstock inventory. The goal of this description is to find out whether it is possible to optimise the fieldstock inventory with regard to the required service levels with these fieldstock guidelines.

Carstock management

For the carstock management, OpCo's Germany, Belgium and Spain use the carstock model. At each of these OpCo's, the technicians are able to adjust the advice given by the carstock model to their own needs. The OpCo's update the carstock model every six months or every year. The stakeholders within the OpCo's have mixed feelings about the carstock model. They indicate that the service levels are met, but they feel that the carstock inventory is not minimised with regard to the target service level. Furthermore, some stakeholders indicate that it is time-consuming to use the model. The advice generated by the model often needs to be adjusted to meet the requirements of the technicians.

OpCo Norway does not use the carstock model. In this OpCo, the technicians can decide themselves which service parts to store in the carstock. However, each carstock is analysed every quarter on two parameters:

1. An overstock analysis is executed for two types of service parts:
    A. Service parts that have not moved for one year or more.
    B. 'One time order parts' that have not moved for three months or more. A 'one time order part' is a part that a technician ordered once because he wanted to add this part to his carstock.
2. An analysis is executed for the parts that cause second visits. If parts cause second visits, these parts are stored in the carstock or in the QRS.

QRS management

None of the selected OpCo's uses strict guidelines to control the QRS's. The responsibility for the QRS is often shared between the service department and the logistics department. In general, the stakeholders indicate that the following categories of service parts are stored in the QRS's; high value parts, parts with a low demand, parts that can break down in a car, and parts that are too large to fit in a car. However, no clear definitions for these categories of parts are used. Each employee may use another definition to determine the QRS-parts. The OpCo's indicate that it would be helpful to have a model or guidelines that help them with the QRS-management.

OpCo Belgium does not have QRS's yet. In the future, OpCo Belgium wants to set up QRS's to meet the increasing customer requirements. Therefore, they feel that the QRS's would be helpful to realize these shorter response times.

Urgent orders

Besides guidelines about the QRS's and carstocks, it is also relevant to find out what guidelines the OpCo's use for the urgent orders. In general, the selected OpCo's use the following guidelines for urgent orders:

- Urgent orders are only ordered if the machine is not functioning or if the machine performs below the quality standards of the customer. A technician is able to urgently order parts in two ways:
    - If the technician is at the customer's site, and does not have the appropriate service part in the carstock or QRS, an urgent order will be made. This urgent order results in a second visit, because the technician needs to return to that customer if the urgently ordered part arrives in the carstock.
    - If the technician knows which parts are needed after a phone call of the customer and does not have that part in the carstock or QRS, the service part can be urgently ordered. Then, the technician can visit the customer after the service part arrived, and repair the machine. This does not result in a second visit.

4.4.3. Conclusions about the fieldstock inventory guidelines

In this section, conclusions about the fieldstock guidelines are drawn based on the analyses in Section 0:

- There is no method available to optimise the inventory in carstocks and QRS's together. Therefore, it is not known whether the applied strategy is optimal with regard to the entire fieldstock inventory. The relation between carstock and QRS is only made if a service part is too large to fit in a carstock or if the demand for that part is somewhat lower.
- All OpCo's use the QRS to store large and expensive parts. However, no strict rules are applied to define 'large' and 'expensive'. Therefore, the employees responsible for the QRS use their own definition. This results in differences between QRS's, also within one OpCo. Therefore, it is not known whether these QRS guidelines are optimal.
- The carstock model is based on single item approach, which means that for all service parts stored in the carstock it is economical justified to store them in the carstock. However, it is not known whether the total carstock inventory is minimised with regard to the required service level. The stakeholders are satisfied with regard to the achieved service levels. However, they feel that the carstock model does not generate optimal inventory levels.

4.5. EOS management

This section analyses the EOS-management at the OpCo's and at LSP. Insufficient EOS-management was mentioned as one of the possible causes for an unbalanced inventory.

There are two moments in time when decisions are taken about the EOS-management:

- Every year, the business units define a strategic plan in which, among other things, a proposal is given of the EOS-dates of all machines. These EOS-dates are based on marketing information, life cycle management and the installed base. The OpCo's can indicate whether they agree with the proposed EOS-dates. This may result in changes of the proposed EOS-dates. These EOS-dates are communicated with LSP.
- LSP generates an overview of all the machines with an EOS-date within the coming two years, and sends this overview to the OpCo's. The OpCo's have the opportunity to indicate whether they still need service parts for these machines, after the proposed EOS-date. If there is a significant amount of OpCo's still wanting service parts for that machine, it can be decided to continue the support for that machine. This decision is taken in co-operation with the business units.

If LSP does not support a machine anymore, the parts belonging to this machine are removed from the RSC. For DR3-OpCo's, LSP is allowed to remove the service parts for which no more service is offered. However, for the DR3-concept no guidelines for EOS-management are defined yet. Currently, there is a project being executed to develop guidelines for EOS-management at the DR3-OpCo's.

The non-DR3 OpCo's decide themselves how to manage EOS service parts. These OpCo's indicate that they take their decisions about EOS based on the installed base within the OpCo. This may result in the situation that an OpCo still services a certain machine, whereas LSP does not support the machine anymore. Furthermore, the service department of an OpCo can also decide to stop the service for a certain machine earlier than the RSC. In this case, the service parts also need to be removed from the fieldstock.

The OpCo's are involved in the decision-making about the EOS-dates, and therefore they can anticipate on these EOS-dates. As was concluded in Section 3.5, the total value of service parts with an EOS-date in the past or in the near future in limited. This means that the OpCo's anticipate on these EOS-dates determined by Océ HQ.

4.6. Conclusions

This section describes the main conclusions of this chapter. The goal of the chapter was to determine the main causes for the unbalanced investment in inventory. Therefore, four possible causes were analysed; the differences in assortment between OpCo's, stock exchange between OpCo's, fieldstock management of the OpCo's, and EOS-management of the OpCo's and LSP.

After the analyses, it can be concluded that the main cause for the unbalanced investment in inventory is the unclear fieldstock guidelines. Currently, there are no clear guidelines available for the optimisation of the entire fieldstock at once. This means that it is not possible to optimise the fieldstock inventory with regard to the required service levels. Although it is questionable whether the carstockmodel and guidelines optimise the carstock inventory, the OpCo's indicate that the achieved service levels are satisfactory. For the QRS inventory, no strict rules are used, and the employees responsible for the QRS use their own guidelines, without knowing whether these guidelines are (close to) optimal. This is also the reason that the OpCo's indicate that it would be helpful to have guidelines for the QRS management.

The three other possible causes for an unbalanced investment may also result in some unbalance of the fieldstock, but their influence is limited. Differences in assortment between the OpCo's hardly influences the fieldstock within one OpCo. The influence of stock transfers between OpCo's is also limited. For OpCo's, it is often faster to order an urgent order at the RSC than to have a stock transfer from another QRS. Therefore, stock transfers between OpCo's may result in a more balanced inventory, but this will only be the case for a small percentage of the orders. The EOS-management has a relatively small influence on the unbalance of the fieldstock. Océ HQ involves the OpCo's in decisions about the EOS-dates, making it possible for the OpCo's to anticipate on these dates, and control the fieldstock with regard to these dates.

5. Analysis results and design requirements

This chapter describes the main conclusions of Chapter 3 and 4, followed by a description of the design assignment and requirements for the model that has to overcome the problems that were found during the analyses in Chapter 3 and 4.

5.1. Results of the analysis

The following research assignment was defined in Chapter 2;

Analyse whether the fieldstock inventory of service parts of Océ is unbalanced and whether this is caused by unclear fieldstock guidelines or by other factors mentioned in the problem cluster.

To execute this research assignment, two types of analyses have been executed. First of all, the current fieldstock inventories have been analysed in Chapter 3. Secondly, the fieldstock management of the selected OpCo's has been analysed in Chapter 4. These analyses lead to the following conclusion:

The service parts' fieldstock inventory of Océ seems to be unbalanced with regard to the investment in service parts. In the QRS's, all categories of service parts are stored, and a significant amount of the inventory of service parts in the fieldstock generates no demand, or hardly any demand. The most likely cause for the unbalanced investment in parts is that the current fieldstock guidelines do not optimise the entire fieldstock, with regard to a target service level. The carstockmodel only focuses on the carstock inventory as a single inventory point. For the QRS's, some guidelines are used, but it is not known whether these guidelines are (close to) optimal with regard to the QRS inventory, or with regard to the integral fieldstock costs.

5.2. Design assignment

To overcome the problems stated in the previous section, the following design assignment is defined:

Design a model to overcome the unbalanced investment in fieldstock inventory. This model should optimise the inventory in the fieldstock with regard to all relevant costs and a target service level. The model must be adjustable by OpCo's to a certain extent. Therefore, an implementation plan should specify how to implement the model.

5.3. Requirements

The requirements stated in this section indicate how the design assignment should be executed to make the model usable for Océ:

- The model should overcome the unbalance of the current fieldstock inventory. The model should result in more clear and (close to) optimal fieldstock guidelines, and thus a more balanced inventory.
- It must be possible to distinguish between machine groups or BU's with regard to service levels. Some machine groups require higher service levels than other machine groups. In the future, it may be possible that service level differentiation is introduced for different machines.
- For the service parts supply chain, the fill rate is the main indicator of the achieved service levels. The fill rate is directly linked to the number of second visits. Therefore, the model should use the fill rate as the main service constraint.

5.4. Conditions

This section discusses the conditions to which the model has to apply. These conditions are not directly linked to the described problem, but are the conditions set by the organisation in order to be able to use the model:

- The model needs to be used by the following stakeholders within Océ:
    - LSP must be able to work with the model, in order to help the OpCo's with their inventory management.
    - The OpCo's need to be able to use the model to calculate the fieldstock inventory.

  This means that different employees within Océ must be able to use the model. These employees usually have a logistics background. Although they do not need to understand all the details of the model, they should be able to understand the basic principles of the model. If employees understand the model, they will accept the outcomes, and they will use the model.
- Because Océ is operating in a dynamic environment, the input parameters need to be updated to new situations regularly. The implementation plan describes how this should be done, and also describes how the model should be implemented in the IT-systems of Océ.

6. Stock control model

This chapter describes the multi-location model that has to overcome the unbalance in fieldstock inventory. Therefore Section 6.1 discusses the concepts behind the model, and how the model fits the service parts supply chain of Océ. Section 6.2 describes the supply chain in mathematical detail.

6.1. Characteristics

For his PhD-study, Kranenburg (2006) developed a stock control model, which allows for lateral transhipments between warehouse locations in a single-echelon structure. This model was developed for the service parts supply chain of ASML by Kranenburg, and adjusted for the service parts supply chain of Vanderlande Industries by Van Sommeren (2007). Furthermore, parts of the model have been adjusted for service parts management at DAF Trucks by Corbijn van Willenswaard (2006).

6.1.1. General description

For his stock control model, Kranenburg (2006) takes a central warehouse and two types of local warehouses into account; regular local warehouses and main local warehouses. All local warehouses serve one or more groups of machines. Main local warehouses can serve as a source for lateral transhipments to other local warehouses. The regular local warehouses do not have this possibility. Lateral transhipments occur in a pre-specified order. This means that if demand for a part occurs at a local warehouse, and this part is not in stock, the main local warehouses are checked in a pre-specified order for the availability of that part. The first warehouse in the pre-specified order that has the part on stock sends a lateral transhipment to the local warehouse where the demand occurred. If none of the warehouses in the pre-specified order has the service part in stock, an emergency shipment from the central warehouse is ordered. All local warehouses apply a basestock policy, which means that a service part is reordered by a regular shipment as soon as it is used. The central warehouse sends these regular orders to the local warehouses. Because all local warehouses are replenished directly from the central warehouse, this is a single-echelon structure. Figure 13 shows all types of stock transfers.

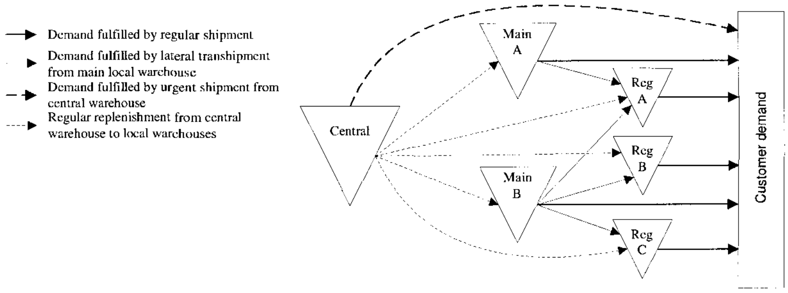


Figure 13; overview of the supply chain described by Kranenburg

Based on this supply chain, Kranenburg developed an algorithm that adjusts the basestock levels at the local warehouses in such a way that the target mean aggregate waiting time for an arbitrary request is met, while minimising the total relevant costs. This means that Kranenburg uses a certain target service level, and optimises the total costs with regard to this target service level. This can be done, because in service-oriented organisations, the offered service level is a strategic choice, based on market conditions and profitability. Decisions about the storage of service parts are taken on a more tactical level in the organisation (Kranenburg, 2006), and are based on the target service levels. This is also the case for Océ, and LSP in particular. The business units set the target service levels, and LSP and the OpCo's have to meet these service levels.

The algorithm has a 'greedy' approach. This means that those service parts are stocked that achieve the highest service levels with the lowest relevant costs. This usually results in the storage of more low-value service parts, and less high-value service parts. This results in the situation that the low-value service parts meet a large percentage of the service level, whereas the high-value parts contribute less to the service levels. This approach can be applied, because the customer's concern is the maintenance of the equipment and not the maintenance of individual parts. This approach guarantees the lowest total relevant cost with regard to the target service level.

The algorithm takes three types of costs into account; costs related to inventory keeping, the additional costs of an emergency shipment compared to a normal shipment, and costs related to lateral transhipments. Because a one-for-one replenishment is assumed, the costs of regular replenishments are not taken into account. This means that if a service part is used, it needs to be replenished, and because of the one-for-one replenishment these costs are incurred anyway. Therefore, only the additional costs of an emergency shipment compared to a normal replenishment are relevant.

6.1.2. Characteristics Océ

The supply chain described in the previous section is almost equal to the service parts supply chain of Océ. Thereby, the carstocks can be considered as regular local warehouses, the QRS's are main local warehouses and the RSC is the central warehouse. If a technician does not have the required service part in the carstock, a lateral transhipment from the QRS is needed to fulfil the demand. If the QRS does not have the part in stock, another QRS or carstock may fulfil the demand. If this is not possible, an urgent order can be ordered at the RSC, which is similar to the emergency shipment in Kranenburg's model.

There are also differences between the supply chain described by Kranenburg, and the service parts supply chain of Océ. First of all, Kranenburg uses the mean aggregate waiting time as service measure. The mean aggregate waiting time can be used as service measure if the waiting time for a repair mainly depends on the waiting time for service parts. For Océ, the waiting time itself largely depends on technician planning and routing. If a required service part is not available nearby, the technician has to return for a second visit. Therefore, the performance measure of the service parts supply chain of Océ should be based on these second visits.

To meet the targets for the second visits, a certain 'first visit' fill rate needs to be met. The first visit fill rate is defined as the probability that an arbitrary request for a service part can be fulfilled, within the time that the technician is at the customer's site for the first time. To meet the demand for a service part within the first visit, the required service part must be stored in the carstock of the technician, or in a fieldstock location that is able to fulfil the demand by a lateral transhipment within the time required for a first visit. This means that this first visit fill rate is the sum of the fill rates of multiple locations that are within the time frame required for the first visit. This time frame depends on the local situation, and is one of the input variables of the model. The OpCo can decide which locations are within the first visit time frame. Figure 14 shows the concept of the first visit fill rate. A similar service measure is described in a study by Caggiano et al (2007), who measure service as the probability that an incoming demand for a part will be satisfied within a specified amount of time. They define this service measure as the channel fill rate, whereby each echelon needs to fulfil a target fill rate to the final customer. For Océ, this means that the channel fill rate of all locations within the time frame of the first visit has to meet the target fill rate.

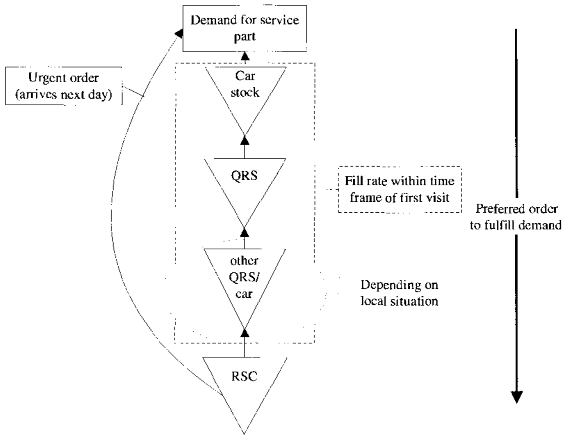


Figure 14; the first visit fill rate

Note that the first visit fill rate can be considered as a special case of the mean aggregate waiting time as service measure developed by Kranenburg, because it also assumes a certain response time. The difference is that the response time is not expressed in time, but in location. This means that all locations that are able to supply the service part are located within the required time frame. Van Sommeren (2007) adjusted the model of Kranenburg with a mean aggregate fill rate as service measure, for the service parts supply chain of Vanderlande Industries.

However, not meeting the first visit fill rate does not lead to a second visit in all cases. The following activities result in not meeting the model's first visit fill rate, but in reality a second visit is avoided:

- Technicians can have lateral transhipments between carstocks or QRS's that were not used within the optimisation. Therefore, the model defines this as not meeting the first visit fill rate, but in reality, a second visit is avoided.

- Technician planners may take the assortment of the technician into account, and send another technician to the customer, if the first technician does not have the required part on stock.
- If a technician knows which parts are needed for a certain repair, and does not have these parts in the carstock, it can be decided to urgently order the part, and visit the customer the next day. The program defines this as not meeting the first visit fill rate, but in reality a second visit is avoided.

The second difference between the service parts supply chain of Océ and the model developed by Kranenburg is that the cars have a limited storage capacity. This characteristic has been researched by several authors, and is defined as a repair-kit problem. See for example Teunter (2006) and Teunter & Haneveld (2002). This repair-kit problem assumes a fixed set of service parts needed to execute repairs. Thereby the total costs are minimised with regard to a target part fill rate or target job fill rate. For these models, often a multi-item approach is applied. However, no methods have been developed that optimise the inventory over multiple locations or multiple echelons. This means that the model developed by Kranenburg needs to be adjusted with regard to the limited storage capacity, and no literature based on repair kits was used.

6.1.3. Key assumptions

This subsection describes the major assumptions underlying the model developed by Kranenburg and how each assumption may influence the outcomes of the model.

All service parts have the same effect on the machine

For all parts that are used in the model, Kranenburg assumes that if a service part breaks down, the corresponding machine is non-operational. This should be true for the low-value service parts as well as for the high-value service parts. For Océ, this is not always the case, because service parts sometimes have to be replaced, whereas the machine is still operational. machine's output does not meet the customer's quality standards However, if a machine does not meet the customer's requirements, it can also be regarded as a non-operational machine.

Service parts that are less critical and not assigned to a particular machine are the EOI-parts. As said before, these parts are not registered in the fieldstock, and are therefore not part of the optimisation model. Furthermore, most cosmetic service parts are ordered at the RSC if needed, and thus not kept in the fieldstock locations. This means that all service parts that are used in the optimisation model have the same effect on the performance of the machines. Thus, it can be concluded that, although not all service parts result in a non-operational machine, it is reasonable to assume that most service parts have the same effect on the machine.

Replenishment lead times are assumed to be independent

Kranenburg assumes that the lead-time for a regular replenishment is independent for different replenishments of the same service part. For Océ, the replenishment lead-time differs per OpCo. OpCo's like Belgium and Germany are being replenished every day, resulting in a replenishment lead-time per service part between one and two days. By assuming a constant usage of service parts over the day, this results in an average lead-time of 1,5 days. However, OpCo's like Norway and Spain are replenished fewer times per week, and the transportation time from the RSC to these OpCo's is longer. This results in longer replenishment lead times, and a less reliable lead-time, due to uncertainty in the transportation times. This may result in replenishment lead-times that are not independent, because different orders are accumulated and replenished simultaneously. However, due to the low demand for most service parts, it is reasonable to assume that the replenishment lead times are independent. More information about the replenishment lead times can be found in Appendix C.

Alfredsson and Verrijdt (1999) have shown that the impact of the probability distribution of the lead times is small for the multi-echelon model they have developed. It is reasonable to assume that this is also applicable for the model developed by Kranenburg, because the model has the same characteristics. Therefore, the algorithm only depends on the average replenishment lead-time, and not on its distribution.

Urgent and lateral transportation costs are assumed to be constant

In order to reduce the complexity of the input parameters, it is assumed that the transportation costs are equal for all service parts. In practice, the transportation costs depend on the physical characteristics of the service parts. For the functioning of the algorithm, it does not matter whether fixed costs are assumed, because it can handle different costs. However, at Océ, it is difficult to assign different transportation costs to service parts. To make the algorithm easier to use, an average transportation cost is assumed for each service part.

The demand for service parts behaves as a Poisson process
The model assumes a Poisson process for the demand for service parts at each location. This assumption is widely used in literature to describe the demand for service parts, because the lifetime of a part within a machine is often distributed according to the exponential distribution. This results in a demand process that can be described by the Poisson process. The most common method to test whether data can be described by a certain probability distribution, is the Chi-square test (Montgomery, 1999).

The Chi-square test was executed for the demand data of OpCo Norway. A minimum demand per service part is required to execute a reliable analysis. 96 Parts had sufficient demand per four weeks to execute a proper Chi-square test. For 82 of those 96 parts (85%) the hypothesis of a Poisson distribution over these four-week periods could not be rejected, with a significance level of 95%. For three service parts, a normal distribution could not be rejected. These service parts had a relatively high demand. For the other eleven service parts, no suitable demand distribution could be found. The demand patterns of these parts may be different because of events like technical changes, changing work procedures or seasonal effects. The model uses data based on a period of six months or one year. Because a Poisson distribution was found for the four-week period, this distribution also applies to the period of six months or one year, which is used by the model. More information about the executed Chi-squared test can be found in Appendix E.

As a conclusion it can be said that the demand for service parts at the fieldstock locations can be described by a Poisson distribution. There is no reason to assume that the demand pattern at other OpCo's is different from the demand patterns at OpCo Norway. The same is true for the service parts that were not used for this analysis. These service parts have the same physical characteristics as the tested service parts, and therefore the same distribution can be assumed.

The RSC has infinite supply
It is assumed that the RSC has infinite supply, for the regular shipments as well as for the urgent shipments. This assumption is related to the reliability of the lead times. When the RSC has infinite supply, the lead times will be more reliable, because the parts can be picked and transported immediately. This results in a reliable replenishment time, and is important if the mean aggregate waiting time is used as service measure. However, because the first visit fill rate is used as service measure, the lead-time for an urgent order is not relevant. For the regular orders, it can be assumed that the lead times are reliable, because most of these service parts are demanded frequently, and thus kept on stock in sufficient quantities in the RSC. This can also be seen at the relatively high service levels offered by the RSC, which can be found in Section 3.1. Therefore, it is reasonable to assume that the RSC has infinite supply.

The maximum carstock inventory is represented by the number of items in the current carstock
As said before, the cars have a limited capacity. Because this restriction is not part of Kranenburg's model, this extra assumption needs to be made. Currently no reliable and complete information is available on the size of service parts or the size of the carstocks. Therefore these data cannot be used for the optimisation, and an approximation needs to be made. It is assumed that the technicians currently use their carstocks on full capacity, meaning that the current amount of service parts in a carstock is the maximum number of parts. Therefore, the maximum carstock inventory is assumed to be the average of the number of items stored in all carstocks. In a similar study, Breure (2007) developed an optimisation model for carstocks. Thereby he also assumed that the current number of service parts stored in the carstocks can be used for the new inventory strategy.

6.2. Model description

This section describes the multi-location model in mathematical detail. It is based on the assumptions described in the previous section. This section starts with a description of the relevant fieldstock characteristics in Subsection 6.2.1. In Subsection 6.2.2, customer demand is described, followed by the description of the relevant costs in Subsection 6.2.3. Subsection 6.2.4 describes the performance measures and the optimisation problem is explained in Subsection 6.2.5. An overview of all variables can be found in the list of variables on page 54.

6.2.1. Fieldstock characteristics

The multi-location model optimises the inventory within a QRS-region. A QRS-region is defined as a geographical region in which a QRS and one or more carstocks are located. Each carstock in this QRS-region is assigned to this QRS. Demand generated by the installed base in that region needs to be fulfilled by these fieldstock locations. This is the situation that is common for most OpCo's. Figure 15 shows a visual presentation of this concept. An overview of all variables can be found on page 54. Other fieldstock configurations are described in Section 7.3.

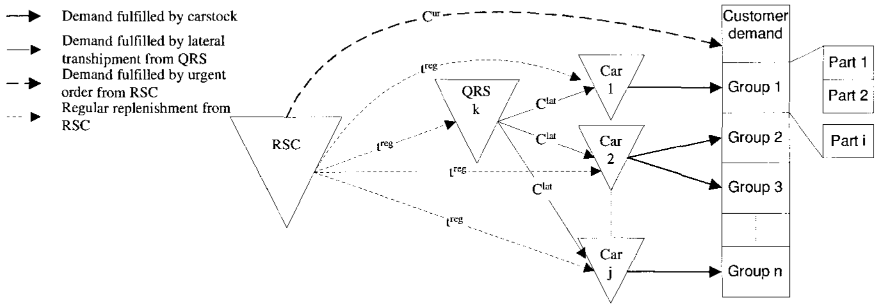


Figure 15; Visual presentation of the multi-location model

As can be seen in Figure 15, there is a set J of fieldstock locations in one QRS-region, including the QRS and all carstocks, whereby each fieldstock location is numbered by $j = 1,...,|J|$. The QRS has number $k(\in J)$. The basestock level for service part i at fieldstock location j is defined as $S_{i,j}(\in \mathrm{N}_0 = \mathrm{N} \cup \{0\})$. Vector $S_i := (S_{i,1},...,S_{i,|J|})$, $i \in I$ represents all basestock levels for part i, over all fieldstock locations. The normal replenishment time from the RSC to the fieldstock locations is equal to t^{reg} for all service parts. Figure 15 shows that there are three possibilities to fulfil the demand for a service part. Hereby, possibility 1 is preferred over possibility 2, and possibilities 1 and 2 over possibility 3:

1. Demand is fulfilled by a carstock. If a technician visits a customer and needs a service part, the first possibility to fulfil this demand is to use a service part stored in the carstock. In total, $\sum_{i \in I} S_{i,j}$ service parts are stored in carstock $j \in J \setminus \{k\}$. The number of parts that can be stored in a carstock is limited due to the size of the car. Therefore, the total number of service parts that can be stored in carstock j is represented by $S_j^{\max}$, $j \in J \setminus \{k\}$.
2. If carstock j cannot fulfil the demand for part i, a lateral transhipment from QRS k may fulfil the demand.
3. If the service part cannot be obtained from one of the fieldstock locations, the part needs to be urgently ordered from the RSC. The service part arrives the next day and the technician may need to make a second visit.

6.2.2. Demand

At Océ, each technician repairs specific machines. This means that for each technician, the total demand can be divided into demand streams based on the machine types this technician repairs. This means that the demand from each machine type can be given a demand category $n \in N$. Each category n is assigned to one carstock, and $N_j(\subseteq N)$ is the subset of categories that is assigned to carstock j. At the QRS's, no autonomous demand takes place, because the QRS's only serve as a backup for the carstock, in case of a stock out of the carstock. This means that no demand categories are assigned to a QRS.

Machines belonging to category n consist of relevant service parts which are numbered $I = 1,...,|I|$. For each part i belonging to group n, a Poisson failure rate is assumed, with a constant rate $m_{i,n}$. This is the demand rate per day. In case of a failure of a service part, the machine is not operational anymore. After replacement of this service part, the machine is operational again. M_n is defined as the total demand for group n; $M_n := \sum_{i \in I} m_{i,n}$. It is assumed that $M_n > 0$.

At Océ, the demand rate for service parts is expressed as the expected demand for a service part for the coming year, denoted by variable . Because technicians do not work all 365 days of the year, demand at a technician only occurs when the technician is repairing machines, and uses the carstock. Therefore, TT is the number of days that a technician uses the carstock. Remark that $m_{i,n} = \frac{ym_{i,n}}{TT}$, with the assumption that technician j services demand category n. However, a QRS is operational during all working days of the year, which is equal to TQ. This means that there is a difference in demand rates between QRS's and technicians. On an arbitrary day, the demand rate at the QRS is equal to the sum of overflow demands of the carstocks that are in use during that day. This means that the demand rate per day at a QRS is lower than the demand rate at a carstock with a rate equal to $\frac{TT}{TQ}$.

In general, demand takes place in single items. However, some service parts are ordered in fixed quantities larger than one. Often, this is reflected in the packing of the service parts. For service parts for which this is not the case, a batch size is introduced. Therefore, variable b_i is defined as the batch size of service part *i*. This batch size reflects the number of items that is needed to repair the machine.

6.2.3. Costs

As said before, the model takes three sorts of costs into account:

1. The cost of a lateral transhipment $C_{j,k}^{lat}$ from QRS *k* to carstock *j*. It is assumed that these costs are equal for all service parts. The costs for a lateral transhipment include the following costs:
   - A. The costs for order handling within the QRS.
   - B. The costs of transportation of the service part from the QRS to the customer.
   - C. The costs for a technician waiting for the service parts to arrive. During the time the technician is waiting for the service parts, the technician could repair other machines and generate revenue for Océ.
2. The additional cost for an urgent order compared to a normal replenishment; C^{ur}. It is assumed that these costs are equal for all service parts, and for all fieldstock locations within the region. This includes the following costs:
   - A. The extra costs of order handling for an urgent order within the department of CS&S.
   - B. The additional costs of picking an urgent order in the RSC. These costs are higher than the picking costs for a regular replenishment.
   - C. The additional costs of the transport of an urgent order. These costs are usually higher than the transportation costs for a regular replenishment.
   - D. The costs of a technician making a second visit to the customer, because the service part was not available. However, not all urgent orders lead to a second visit. Therefore, the costs for a second visit need to be adjusted in case the technician avoids a second visit.
3. Inventory costs for part *i* at location *j*; $C_{i,j}^{h}$ for one year. The inventory costs consist of two components:
   - A. Holding costs *h*; This cost component represents the opportunity costs of the investment in service parts. Océ could have used this investment for other opportunities that generate revenue. This component is expressed as a percentage of the value of the service part. At Océ, this value is expressed in the standard price (SP_i). Therefore, $SP_i \cdot h$ gives the holding costs per part *i*. For non-DR3 OpCo's the value of service parts is expressed in the Inter Company Price (ICP). The holding costs do not depend on the location where part *i* is stored.
   - B. Storage costs; the costs of renting or using a location for storing a part. This cost component does not depend on the value of a part, but on the storage location and the service part. Therefore $C_{i,j}^{s}$ may have a different value for each service part, and for each storage location.

   This results in the following formula for the inventory costs for part *i* at location *j*; $C_{i,j}^{h} = (SP_i \cdot h + C_{i,j}^{s})b_i$.

6.2.4. Performance measures

With regard to the algorithm, three types of fill rates are relevant. These fill rates represent the possibilities of demand fulfilment stated in Figure 15 and Figure 16.

1. $\beta_{i,j}(S_i)$; Fraction of the demand for part *i* at fieldstock location *j* that is delivered immediately upon request. This is also called the (item) fill rate from this location.
2. $\alpha_{i,j,k}(S_i)$; Fraction of the demand for part *i* at carstock *j* that is delivered from QRS *k* by a lateral transhipment.
3. $\theta_{i,j}(S_i)$; Fraction of the demand for part *i* at location *j* that is delivered from the RSC as an urgent shipment.

In total, this results in $\beta_{i,j}(S_i) + \alpha_{i,j,k}(S_i) + \theta_{i,j}(S_i) = 1$, which means that all demand is fulfilled. The total fraction of the demand for part *i* that can be fulfilled within the first visit from carstock *j* is equal to: $\beta_{i,j}^{total}(S_i) = \beta_{i,j}(S_i) + \alpha_{i,j,k}(S_i)$. This can also be seen in Figure 16.

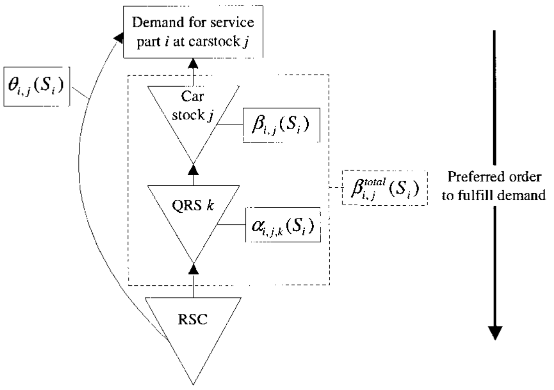


Figure 16; schematic overview of the performance measures

The average first visit fill rate for machine group *n* is equal to $\sum_{i\in I}\frac{m_{i,n}}{M_n}\beta^{total}_{i,j}(S_i)$, and the target for the service parts supply chain is to keep this average fill rate above the target fill rate β^{obj}_n, for each group *n*.

6.2.5. Optimisation problem

The variables that were described in the previous sections can be used to derive the optimisation problem. Solving this optimisation problem gives the optimal basestock levels for the QRS-region. Within one QRS-region, the total inventory costs for part *i* per year are equal to;

$$\sum_{j\in J} C^h_i S_{i,j} \tag{1}$$

The total costs related to transportation for part *i* per year per QRS-region are equal to;

$$\sum_{j\in J\setminus\{k\}} M_{i,j}(C^{lat}_{j,k}\alpha_{i,j,k}(S_i)+C^{ur}\theta_{i,j}(S_i)) \tag{2}$$

Equation (2) is equal to the sum of the expected costs for lateral transhipments and the expected costs for urgent orders. The sum of equations (1) and (2) represents the total relevant yearly costs for part *i*:

$$C_i(S_i)=\sum_{j\in J} C^h_i S_{i,j}+\sum_{j\in J\setminus\{k\}} M_{i,j}(C^{lat}_{j,k}\alpha_{i,j,k}(S_i)+C^{ur}\theta_{i,j}(S_i)) \tag{3}$$

The final goal for the service parts supply chain of Océ is to meet the required target fill rate in each QRS-region. This results in the following mathematical formulation of the objectives of the model;

$$\text{Min} \quad \sum_{i\in I} C_i(S_i)$$

$$\text{Subject to:} \quad \sum_{i\in I}\frac{m_{i,n}}{M_n}\beta^{total}_{i,j}(S_i)\geq\beta^{obj}_n \;,\; j\in J, n\in N_j$$

$$\sum_{i\in I} S_{i,j}\leq S^{\max}_j \;,\; j\in J\setminus\{k\}$$

$$S_{i,j}\in \mathrm{N}_0 \;,\; i\in I, j\in J$$

This means that the total relevant costs have to be minimised, with regard to a target first visit fill rate, and with regard to the maximum number of parts in each carstock. Solving this problem in an exact way requires a lot of calculation time or is sometimes even impossible, due to the large amount of data for most real-life situations. Therefore Kranenburg (2006) developed a method that calculates the close-to-optimal solution for this problem. This method is described in the next chapter.

7. Optimisation program

To solve the optimisation problem stated in the previous chapter, Kranenburg developed two algorithms, which can be combined into one optimisation program. A schematic overview of this program, and the input and output variables are shown in Figure 17.

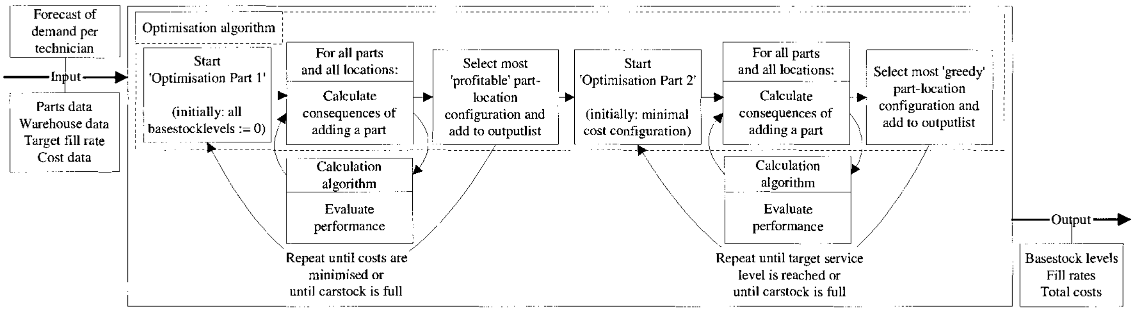


Figure 17; overview of the optimisation program

Figure 17 shows that the program consists of two algorithms; a calculation algorithm in which the performance of the current configuration is evaluated, and the optimisation algorithm that determines the optimal solution. The optimisation algorithm uses the calculation algorithm, to calculate the performance of different configurations and repeats these calculations until the optimal configuration is reached.

The optimisation algorithm consists of two parts. In 'Optimisation Part 1' service parts are added to the fieldstock until the minimal cost configuration is reached. 'Optimisation Part 2' adds parts to the fieldstock until all target fill rates are met, or until all fieldstock locations are full. The calculation algorithm is explained in more detail in Section 7.1, and the optimisation algorithm is explained in more detail in Section 7.2. Section 7.3 discusses the extensions that can be made to the program, Section 7.4 describes the programming language in which the program is programmed. This chapter ends with a discussion about the validation and verification in Section 7.5. An overview of all variables can be found on page 54.

7.1. Calculation algorithm

In his PhD-thesis, Kranenburg (2006) describes an exact evaluation policy that can be used to evaluate the supply chain described in the previous sections. This method is based on Markov processes, and can be used to evaluate the situation exactly. As said before, for real-life situations at many service organisations, this method takes a lot of computation time, and is in some cases impossible. Especially the existence of many local warehouses influences the calculation time significantly. In order to reduce complexity and computational times, an approximate evaluation method was developed by Kranenburg. For this evaluation, Kranenburg uses the Erlang loss model, which is based on the Markov process displayed in Figure 18.

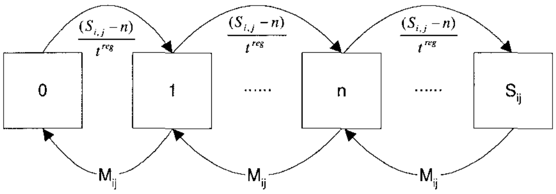


Figure 18; Markov process representing inventory position for part i *in a storage location*

The Markov process in Figure 18 shows the process of changing physical stock in a storage location. Within the boxes, the inventory level is shown. This inventory level varies between 0 and basestock level $S_{i,j}$. If a demand for a service part occurs, the inventory position decreases with 1. The demand rate is equal to demand rate $M_{i,j}$, which can be seen in the lower part of Figure 18. If the inventory position decreases, a regular replenishment is executed, in order to reach base stock level $S_{i,j}$ again. This regular replenishment takes time t^{reg} to arrive at the fieldstock location. Therefore, an increase in the inventory position equals rate $\frac{(S_{i,j}-n)}{t^{reg}}$, which can be seen in the upper part of the figure. By using the Erlang loss model the fraction of the demand that cannot be fulfilled from stock can be calculated. The Erlang loss model is equal to; $L(n,\rho)=\frac{\rho^n/n!}{\sum_{x=0}^{n}\rho/x!}$. Thereby, n represents the number of servers in the system, and ρ the occupation rate.

By using this Erlang loss model, Kranenburg developed an algorithm that can be used to calculate different performance measures for each service part $i\in I$. The steps of this algorithm are explained in the following subsections. A more detailed description of the algorithm and its derivation can be found in Appendix F.

Step 1; fill rate per carstock
For the analyses of the carstocks, the fill rate can be determined in an exact way by using the Erlang loss model. For this, the inventory position is considered as the number of servers in the system, and $M_{i,j}t^{reg}$ as the occupation rate. This results in the following formula that is used to calculate the fill rate for all carstocks $j\in J\setminus K$; $\beta_{i,j}(S_i)=1-L(S_{i,j},M_{i,j}t^{reg})$

Step 2; demand at the QRS
If a demanded item cannot be delivered out of the carstock, the next possibility is to fulfil the demand by a lateral transhipment from the QRS in that region. The demand for a lateral supply from carstock $j\in J\setminus K$ to QRS k has demand rate $\frac{TT}{TQ}(1-\beta_{i,j}(S_i))M_{i,j}$. This so-called 'overflow demand' is assumed to behave as a Poisson process. As can be seen, the overflow demand is adjusted by the factor $\frac{TT}{TQ}$, which represents the difference in working days between QRS and technicians. The total demand from all carstocks to QRS k is equal to $\tilde{M}_{i,k}:=M_{i,k}+\sum_{j\in J\setminus\{k\}}\frac{TT}{TQ}(1-\beta_{i,j}(S_i))M_{i,j}$. However, because no autonomous demand takes place at the QRS's, $M_{i,k}=0$, and the total demand at QRS k is equal to; $\tilde{M}_{i,k}:=\sum_{j\in J\setminus\{k\}}\frac{TT}{TQ}(1-\beta_{i,j}(S_i))M_{i,j}$.

Step 3; fill rate of the QRS
Because this step requires the calculation of the fill rate from the RSC to the QRS, it is divided into steps A and B:

Step A The demand from QRS k to the RSC, represented by $\theta_{i,k}$, depends on the base stock level at QRS k, and on the demand from the carstocks to QRS k. By assuming a Poisson overflow demand process, the demand from QRS k to the RSC can be calculated by using the Erlang loss model; $\theta_{i,k}(S_i):=L(S_{i,k},\tilde{M}_{i,k}t^{reg})$.

Step B By applying the same concept as was done in the previous step, the fill rate for QRS k can be calculated by; $\beta_{i,k}(S_i):=1-L(S_{i,k},\tilde{M}_{i,k}t^{reg})$

Step 4; fill rate of the QRS and RSC to the carstock
As the last step, the fill rate from QRS k to carstock j, $\alpha_{i,j,k}(S_i)$, can be calculated by multiplying the 'non-fill rate' of carstock j and the fill rate for QRS k; $\alpha_{i,j,k}(S_i):=(1-\beta_{i,j}(S_i))\beta_{i,k}(S_i)$. Then, the fill rate from the RSC to carstock j can be calculated by multiplying the 'non-fill rate' of carstock j and the 'non-fill rate' of QRS k. The 'non-fill rate' of the QRS is equal to the fill rate from the RSC to the QRS, and therefore; $\theta_{i,j}(S_i):=(1-\beta_{i,j}(S_i))\theta_{i,k}(S_i)$.

7.2. Optimisation algorithm

This section describes how the optimisation algorithm optimises the fieldstock inventory with regard to the required service levels and relevant costs. In Subsection 7.2.1, a general description of the algorithm is given, and the changes that were made to the algorithm developed by Kranenburg are described. Subsection 7.2.2 describes the algorithm in a mathematical way.

7.2.1. General description

To optimise the basestock levels with regard to a target first visit fill rate, an optimisation procedure needs to be developed. As said before, Kranenburg (2006) developed an algorithm that calculates the (close to) optimal basestock levels under a mean aggregate waiting time constraint. Van Sommeren (2007) adjusted this algorithm to an algorithm that uses the mean aggregate fill rate per location as target service level. This is quite similar to the situation at Océ, and therefore the algorithm developed by Van Sommeren will be used as base for the optimisation algorithm for Océ.

The algorithm developed by Kranenburg can be described in three steps:

1. In the initialisation step, all base stock levels of all service parts are set to zero.
2. For the second step, base stock levels are increased if and as long as it does not increase the total relevant costs. This step is executed for each service part separately, because costs and waiting times depend on the basestock level of this service part only. This step has a greedy approach; the basestock of the location is increased by one if that location gives the largest cost decrease.
3. The basestock levels are iteratively increased with the service part that provides the largest increase in fill rate per unit cost increase. Base stock levels are increased until the target fill rate is reached. This step has a greedy approach with regard to both the service parts and the locations. This means that for each combination of service part and location the total increase in costs and increase in fill rate is calculated.

In Section 6.1.2, the differences between the supply chain described by Kranenburg and the service parts supply chain of Océ were described. These differences have the following consequences for the algorithm:

1. Kranenburg uses the mean aggregate waiting time as target service level. As said before, for Océ the first visit fill rate is a more suitable service measure. Therefore the algorithm needs to be adjusted, and β_n^{obj} is the service measure to be used as input for the optimisation.
2. The carstocks at Océ have a limited capacity. This has some consequences for the execution of the model:
   A. The first consequence is that for each carstock a maximum number of items needs be defined. This means that for steps 2 and 3 of the algorithm, a restriction needs to be introduced that limits the total basestock level of each carstock. This was also mentioned in Section 6.2.
   B. Because the model developed by Kranenburg assumed infinite capacity for all fieldstock locations, the most cost efficient basestock levels are calculated for each service part separately. Due to the capacity restrictions of the carstocks, the procedure developed by Kranenburg may result in the situation that the carstocks are full before the most cost-efficient basestock levels of all service parts are calculated. This results in a suboptimal outcome of the algorithm. Therefore, it is required to adjust the algorithm in such a way that a greedy approach is applied over all service parts and all locations. This means that the cost decrease over all service parts and over all locations needs to be calculated. Then, the configuration with the largest cost decrease can be selected.
   C. The third step of the algorithm assumes that the total relevant costs increase when executing this step, because the most cost efficient situation was reached after the second step. For Océ, this may not be the case, because the carstock inventory may be full before reaching the most cost-efficient basestock levels. Therefore, only for those carstocks that are not full yet, the required basestock levels need to be calculated. This means that full carstocks are excluded from the greedy calculation.

7.2.2. Mathematical description

The adjustments to the algorithm of Kranenburg, described in the previous subsection, result in the algorithm described in this subsection.

In order to calculate the effects of different basestock levels on the total costs, variable e_j is defined. This variable represents a row vector of size $|J|$ with the j-th element equal to 1, and all other elements equal to 0. This vector is used to calculate cost levels for different basestock levels of part i at fieldstock locations j. The cost differences of these different basestock levels can be calculated by using $\Delta C(i,j) := C_i(S_i + e_j) - C_i(S_i)$. Thereby, $\Delta C(i,j)$ represents the cost difference if the basestock level for part i at local warehouse j would be increased by one, at a given vector S_i. Then, $C_i(S_i + e_j)$ and $C_i(S_i)$ can be calculated by using equation (3), described in Section 6.2.5.

Besides the effects on the total costs, it is also required to calculate the effects of the increase in basestock level for the mean aggregate first visit fill rate $\beta_{i,j}^{total}$. This is calculated by using the following equation;

$$\Delta W(i',j') := \sum_{j\in J}\sum_{n\in N_j}\left[\sum_{i\in I}\frac{m_{i,n}}{M_n}\beta_{i,j}^{total}(S_i)-\beta_n^{obj}\right]^+ - \sum_{j\in J}\sum_{n\in N_j}\left[\sum_{i\in I\setminus\{i'\}}\frac{m_{i,n}}{M_n}\beta_{i,j}^{total}(S_i)+\frac{m_{i',n}}{M_n}\beta_{i,j}^{total}(S_{i'}+e_{j'})-\beta_n^{obj}\right]^+$$

With, $[a]^+ := \max\{0,a\}$ This equation calculates the increase in fill rate $\beta_{i,j}^{total}$ for all parts *i*, for all groups *n* and for all fieldstock locations *j* if the basestock level of part *i* is increased by one, at fieldstock location *j*.

Then, the ratio $R(i,j) := \dfrac{\Delta W(i,j)}{\Delta C(i,j)}$ calculates the increase in mean aggregate first visit fill rate with regard to the extra costs of this increase in basestock level, and thus calculates the increase in first visit fill rate per euro.

This results in the following algorithm:

```
Step 1:         Set $S_{i,j} := 0$, $i \in I, j \in J$

Step 2:
    Step 2a:    Calculate $\Delta C(i,j)$, $i \in I, j \in J' := \{j \in J \mid \sum_{i\in I} S_{i,j} < S_j^{\max}\}$
    Step 2b:    While min $\{\Delta C(i,j) \mid i \in I, j \in J'\} \le 0$:
                    1. Determine $\hat{i}$ and $\hat{j}$ such that $\Delta C(\hat{i},\hat{j}) \le \Delta C(i,j)$, $i \in I, j \in J'$
                    2. Set $S_{\hat{i},\hat{j}} := S_{\hat{i},\hat{j}} + 1$
                    3. Calculate $\Delta C(i,j)$, $i \in I, j \in J' := \{j \in J \mid \sum_{i\in I} S_{i,j} < S_j^{\max}\}$

Step 3:
    Step 3a     Calculate $R(i,j)$, $i \in I, j \in J' := \{j \in J \mid \sum_{i\in I} S_{i,j} < S_j^{\max}\}$
    Step 3b     While max $\{R(i,j) \mid i \in I, j \in J'\} > 0$:
                    1. Determine $\hat{i}$ and $\hat{j}$ such that $R(\hat{i},\hat{j}) \ge R(i,j)$, $i \in I, j \in J'$
                    2. Set $S_{\hat{i},\hat{j}} := S_{\hat{i},\hat{j}} + 1$
                    3. Calculate $R(i,j)$, $i \in I, j \in J' := \{j \in J \mid \sum_{i\in I} S_{i,j} < S_j^{\max}\}$

Step 4:         Set $S_{i,j} := S_{i,j} \cdot b_i$, $i \in I, j \in J$
```

To prevent (very) high basestock levels for service parts, an extra restriction is introduced; if the fill rate for service part *i* at location *j* is equal to 0,998 or higher, the basestock level will not be increased anymore. In practice, increasing the basestock level above 0,998 will not have an effect on the first visit fill rate.

7.3. Extensions to the basic program

The fieldstock configuration described in Chapter 6 represents the current situation at many OpCo's. In this situation, the QRS is the only source for lateral transhipments. However, there are also OpCo's with different fieldstock settings. In this section the differences in fieldstock settings are explained, and the consequences for the basic model are described. In Chapter 8, the performances of these different settings are compared with the basic setting.

These settings have consequences for the optimisation program with regard to the lateral transhipments between fieldstock locations. For the basic fieldstock setting, only lateral transhipment from the QRS to a carstock is possible. However, the following fieldstock settings are also possible:

- OpCo's with multiple QRS's within the time frame for a first visit. This makes it possible to have lateral transhipments of service parts from multiple QRS's. This may for example be the case for the Netherlands, where the QRS's are relatively close together.
- OpCo's without QRS's. For example, OpCo Belgium does not have QRS's, and therefore only the carstock inventory needs to be optimised. A possibility for these OpCo's is to have lateral transhipments between carstocks, and optimise these carstocks with regard to these transhipments.

These lateral transhipments may already be in use at an operational level. However, if these possibilities are also used to optimise the fieldstock inventories, it may result in a better performance of the fieldstock. Therefore, these possibilities are compared with the results achieved in the current situation in Chapter 8.

These different fieldstock settings result in a couple of consequences for the evaluation algorithm. First of all, more QRS's or carstocks need to be defined as main warehouses. For this, it is also possible that a carstock is defined as main warehouse, if it serves as a source for lateral transhipments to other carstocks. This means that carstocks can be numbered as $k \in K$. Each regular warehouse $j \in J \setminus K$ is assigned to a main local warehouse $k \in K$. This main local warehouse is the first possibility to provide a lateral transhipment, and it is denoted as k_j.

Another consequence is that it is also possible to have lateral transhipments between main local warehouses. Vector $\sigma(k) := (\sigma_1(k),..,\sigma_{|K|-1}(k))$ shows the pre-specified order of mains for main warehouse *k* which are checked for the availability of demanded part *i*. Thereby, each main local warehouse other than *k* appears exactly once in this vector. This means that $\sigma_1(k)$ is the first main warehouse that is checked for the demanded part *i*, $\sigma_2(k)$ is the second main warehouse that is checked, etcetera. Furthermore, $K(k,\tilde{k}) \subset K$ is defined as the subset of main local warehouses with a lower position number than main local warehouse $\tilde{k}$, in the pre-specified order for main *k*. This means that all predecessors of $\tilde{k}$ are part of subset $K(k,\tilde{k}) \subset K$.

For the basic setting, the fraction of the demand for part *i* at carstock *j* delivered by QRS was equal to $\alpha_{i,j,k}(S_i)$. For the extended model, the demand at carstock *j* can be fulfilled by more than one location, and therefore, $A_{i,j}(S_i) := \sum_{k \in K, k \neq j} \alpha_{i,j,k}(S_i)$ represents the total fraction of the demand delivered by main warehouses assigned to carstock *j*. This is also shown in Figure 19.

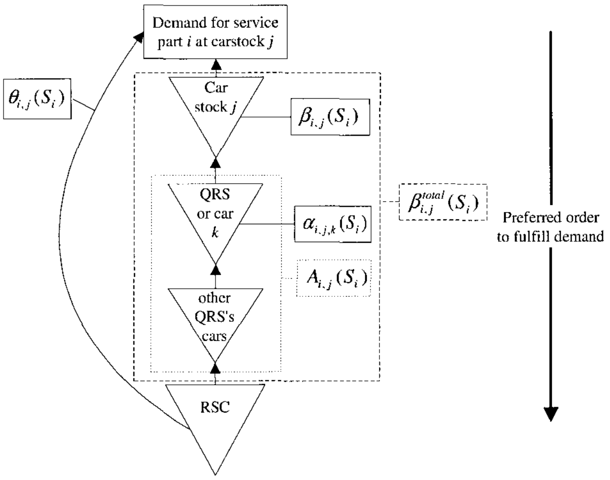


Figure 19; schematic overview of the service measures for extended settings

This has consequences for the calculation algorithm, because the extra flow of service parts between main warehouses results in a more complicated calculation of the program's output. Therefore, four additional steps replace step C of the calculation algorithm. Appendix F describes this algorithm and its derivation in more detail.

7.4. Programming language

In order to execute the program described in the previous sections, the program was programmed into a software package. The programming language selected for the program is Delphi. This language is chosen for the following reasons:

- Delphi has a relatively simple structure, and is therefore easy to understand. The steps taken in the optimisation and evaluation algorithm can be transformed into Delphi-language in a straightforward manner.
- Kranenburg (2006) and Van Sommeren (2007) programmed their algorithms also in Delphi. This means that parts of the program were already available, and no time was lost by re-developing existing programs.
- Delphi makes it relatively easy to adjust the input files. For this project, the input files are Excel-files, but the implementation at Océ may require other input files, such as Access or SAP-files.

7.5. Verification and validation

To check whether the program can be used at Océ, and whether the program optimises the fieldstock inventory as it should, this section describes the verification and validation of the program. Subsection 7.5.1 describes the verification, followed by a description of the validation in Subsection 7.5.2.

7.5.1. Verification

The goal of the verification of a program is to check whether the program behaves as it should. A number of actions were executed to verify the optimisation program. First of all, the program was debugged, and the error messages that appeared were tackled. Next, each module of the program was tested by checking whether the modules performed as expected. This was done by using simple scenarios that make it easier to check whether the program performs as intended. The third and last check was to run the program with extreme scenarios. By using extreme input variables, it can be checked whether the program performs well under all conditions. Because all actions resulted in the predicted outcomes, the program was successfully verified.

7.5.2. Validation

Validation is a broader concept then verification. The goal of validation is to check whether the program represents the reality of the relevant aspects of the system. The validation requires a validation model that takes actual orders and deliveries into account, with time aspects. The optimisation program does not take time into account, because it uses probabilities that specific events occur. If the results of the validation model are compared with the optimisation program, it can be checked whether the optimisation program correctly represents reality.

Therefore, a validation model was developed in Excel. This validation model requires two input variables. First of all, it contains an event list, in which demand and delivery data for service parts are shown. This event list is based on the date that these events occurred. The second input variable is the basestock levels of the service parts at that location. By using the event list and the basestock levels, it can be calculated what the fill rate of the validation model is with those basestock levels. Because time is taken into account, this is the fill rate that would also occur in reality. This results in a validation model that represents the situation that would occur if those particular basestock levels are chosen.

To compare the results of the validation model with the results of the optimisation model, the following procedure is applied; first, demand data of a carstock are used as input for the optimisation model. Then, a specific target fill rate is used as input, and the optimisation model calculates the optimal basestock levels with regard to this target fill rate. Next, these basestock levels are used as input for the validation model. The event list is also added to the validation model. Then, the fill rate can be calculated. This fill rate is based on actual demand data, and can therefore be compared with the fill rate calculated by the optimisation model. If there is only a small difference between these fill rates, the optimisation program can be regarded as a good representation of the actual situation. An overview of the validation procedure is given in Figure 20.

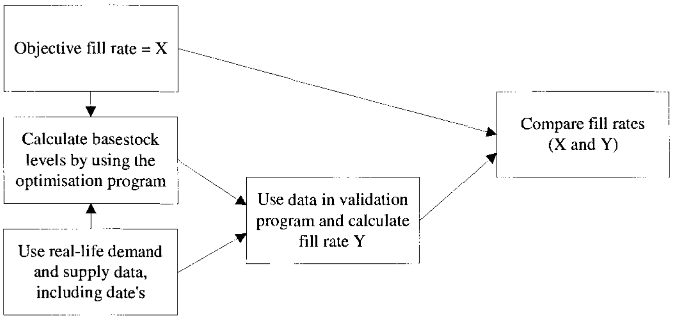


Figure 20; Outline for the validation of the optimisation program

Because it is essential to validate the time aspects of the optimisation program, it is not required to validate the flow of parts between inventory locations. The flow of parts between locations within one QRS-region does not depend on time aspects. Therefore, only carstocks were validated. In total, three different carstocks were validated, which were randomly picked from OpCo Germany. The demand data over 2007 have been used. Three different target service levels have been used to validate the model. The results of the validation can be found in Table 3. The column 'Optimisation input' shows which value was used as input variable for the first visit fill rate. The column 'Optimisation output' shows the output of the first visit fill rate of the optimisation program. In this case, the output was always equal to the input, but some overshoot may occur in other situations. The last column shows the output of the validation model. By comparing these values with the values of the optimisation output, the optimisation program can be validated.

Location	Objective fill rate	Optimisation output	Validation output
Carstock 1678	99,0 %	99,0 %	99,7 %
	95,0 %	95,0 %	95,5 %
	90,0 %	90,0 %	89,7 %
Carstock 2105	99,0 %	99,0 %	99,1 %
	95,0 %	95,0 %	94,7 %
	90,0 %	90,0 %	88,9 %
Carstock 1708	99,0 %	99,0 %	99,6 %
	95,0 %	95,0 %	95,3 %
	90,0 %	90,0 %	90,2 %

Table 3; overview of the validation

As can be seen in Table 3, the results of the validation model and the optimisation program are relatively close together. This means that the optimisation program represents the actual situation well, and that the results of the optimisation model are close to the results that would occur in reality. There is no reason to assume that other carstocks behave differently than the carstocks used for the validation.

8. Design results

To find out whether the optimisation program performs better than the current methods of inventory management, the program was tested with actual data, and compared with the current situation for one region. Section 8.1 describes the comparison procedure and the results of the comparison. Section 8.2 analyses the characteristics of the results of the program. In Section 8.3 the consequences of different fieldstock settings are described, followed by a sensitivity analysis in Section 8.4. To test the program for more regions, Section 8.5 contains an optimisation of another region.

8.1. Basic model

To find out whether the multi-location model performs better than the current inventory management, the performance of the current configuration needs to be compared with the performance achieved by the configuration given by the optimisation program. To be able to make a comparison between both configurations, the procedure in Figure 21 is used:

1. Current basestock levels of all fieldstock locations and the actual demand per service part per location are obtained. The basestock levels are used to determine the current investment in inventory.
2. With the obtained demand data and basestock levels, the current first visit fill rate per carstock can be calculated.
3. The first visit fill rates obtained in the previous step serve as the objective fill rates for the execution of the optimisation program. By using the same demand data as the previous step, and the objective fill rates, the basestock levels for all service parts per location are calculated by the optimisation program. This results in a certain required investment in inventory.
4. By comparing the total investment in inventory for the current situation, with the total investment for the multi-location model, the difference between these two options can be found.

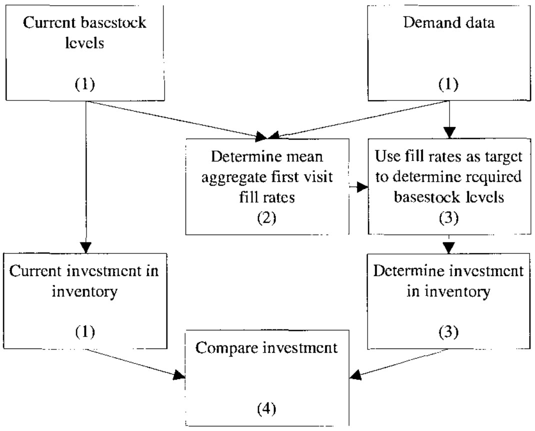


Figure 21; overview of the method used to compare the performance of situation 1 and 2

This procedure was used to compare the current configuration in Competence Centre (CC) Ost in Germany with the configuration given by the program. This region was randomly picked from OpCo Germany, because it is relatively easy to gather data from this OpCo. CC Ost has 32 relevant technicians, one QRS and 2400 demanded service parts. For this procedure, only service parts are used that generated demand during that period. For Sections 8.1 and 8.2 it is assumed that all technicians have access to the QRS. In reality, this may not be the case, because some technicians may be located too far from the QRS to have lateral transhipments. Demand data from the period December 2006 until October 2007 have been used.

The comparison procedure is used to calculate the results that are shown in Subsection 8.1.1. The procedure can also be used to compare the service levels with regard to an equal investment in inventory. The results of this comparison are described in Subsection 8.1.2.

8.1.1. Comparison of investment

Table 4 shows the results of the comparison of the current configuration with the output of the optimisation program. The column 'current configuration' shows the performance of the current configuration and the column 'comparable configuration' shows the performance of the optimisation program. The column 'optimal configuration' shows the performance of the cost optimal configuration.

	Current configuration	Comparable configuration	Optimal configuration
Average fill rate from car	0,704	0,687	0,990
Average first visit fill rate	0,735	0,736	0,998
Investment *(normalized)*	100	33,47	167,87
Total costs *(normalized)*	100	101,02	6,83

Table 4; overview of the comparison of the investment in parts with an equal first visit fill rate

As can be seen in Table 4, the current configuration gives an average first visit fill rate of 0,735. The optimisation program achieves the same first visit fill rate with an investment in service parts that is 66,5% lower than the current investment.

However, the comparable configuration does not lead to the lowest total relevant costs. As said before, the algorithm consists of two steps. After the first step, the cost optimal configuration is reached, and in the second step service parts are added until the target first visit fill rate is met. The comparable configuration was reached before the first step of the algorithm was finished. When the algorithm is able to continue the process until the first step is finished, this results in the performance shown in the column 'optimal configuration'. This configuration can be achieved by a higher investment in service parts than the current configuration. This results in total costs that are 93,2% lower than the current costs.

Remarkable about the outcomes of the cost optimal configuration are the high service levels in relation to the low total relevant costs. This means that the second step of the algorithm does not need be executed, because the first step of the algorithm already leads to first visit fill rates that are higher than the target first visit fill rates. The explanation for this is that the inventory costs are low compared to the lateral and urgent order costs, making it relatively cheap to store service parts. This also explains the high investment in service parts compared to the current investment. The cost structure is explained in more detail in Section 8.2.

8.1.2. Comparison of service levels

The previous section compares the investment in service parts with regard to an equal first visit fill rate for the current configuration and the program's configuration. This section compares the first visit fill rate of the current configuration with the first visit fill rate that would be achieved by the program, with an investment that is equal for both configurations.

	Current configuration	Comparable configuration	Optimal configuration
Average fill rate from car	0,704	0,897	0,990
Average first visit fill rate	0,735	0,941	0,998
Investment *(normalized)*	100	100	167,87
Total costs *(normalized)*	100	27,66	6,83

Table 5; overview of the comparison of service levels with an equal investment

Table 5 shows that with an investment equal to the current investment, the average first visit fill rate can be increased from 0,735 to 0,941. Furthermore, with the same investment in service parts, the total relevant costs are significantly lower than for the current configuration. However, as said before, the total relevant costs can be decreased more, with a higher investment in parts. This is shown in the column 'optimal configuration'.

8.2. Characteristics of the results

This section describes the main characteristics of the outcomes of the program, and the concepts behind these outcomes. Subsection 8.2.1 shows the cost structure of CC Ost, and explains the high service levels in relation to the low costs. Subsection 8.2.2 describes which service parts have to be stored, followed by a description of the location where these parts need to be stored in Subsection 8.2.3. Subsection 8.2.4 analyses the performance of the program for different machines.

8.2.1. Cost structure

One of the remarkable outcomes of Section 8.1 was that the optimal configuration is achieved with a relatively high investment in service parts, leading to low total relevant costs compared to the current configuration. The reasons for these characteristics are explained in this section.

Figure 22 shows the cost structure, with regard to the number of items that can be stored in the fieldstock of CC Ost. On horizontal axis, the number of added items to the fieldstock is shown, with the corresponding costs on the left vertical axis, and the resulting first visit fill rate on the right vertical axis. For example, if 60 items *(normalized)* are stored in the fieldstock of CC Ost, this results in an average first visit fill rate of 0,986, total costs equal to 252 *(normalized)*, lateral plus urgent order costs equal to 213 *(normalized)*, and inventory costs equal to 41 *(normalized)*.

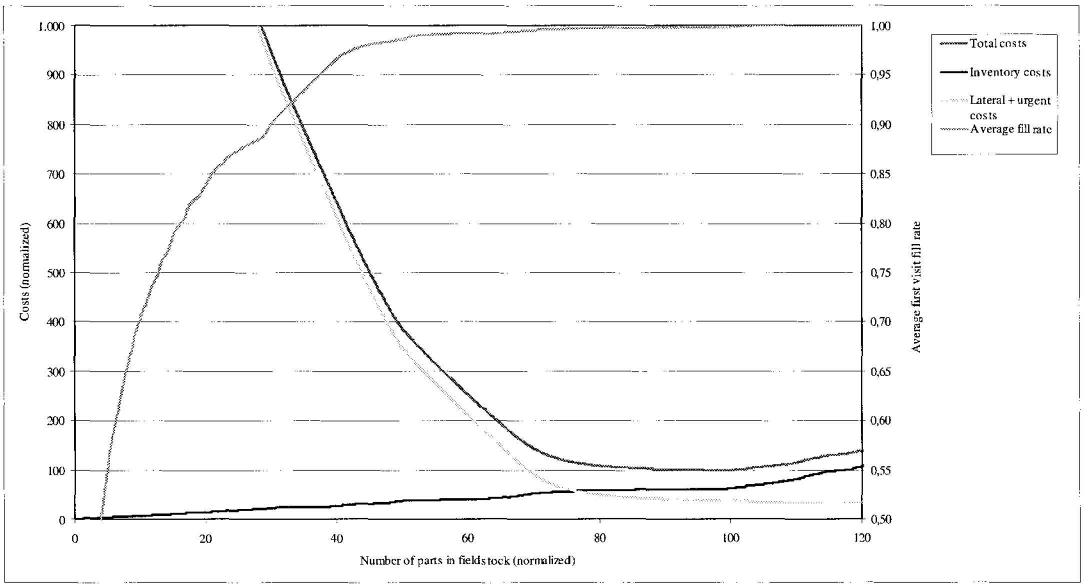


Figure 22; cost structure of the fieldstock of CC Ost (normalized)

Figure 22 shows that the inventory costs are small compared to the costs for lateral and urgent orders. At a fill rate of 0,997, the cost optimal configuration is reached, which results in 100 *(normalized)* items to be stored in the fieldstock. This means that it is not worthwhile to store less than 100 *(normalized)* items in CC Ost, because this leads to higher total costs, at a lower first visit fill rate. Currently, 109 *(normalized)* items are stored in the fieldstock, and a fill rate of 0,74 is achieved.

8.2.2. Investment in service parts

One of the results of Section 8.1 is that with a relatively high investment in service parts the total relevant costs are minimised. This subsection describes the service parts that have to be stored to achieve this configuration.

As Table 4 shows, the total investment in service parts for the optimal configuration is 68% larger than the current investment. The number of items that need to be stored to achieve the cost optimal configuration is equal to 100 *(normalized)*, whereas currently 109 *(normalized)* items are stored. To compare the value of the stored items for both solutions, Figure 23 shows the value of the stored items in more detail.

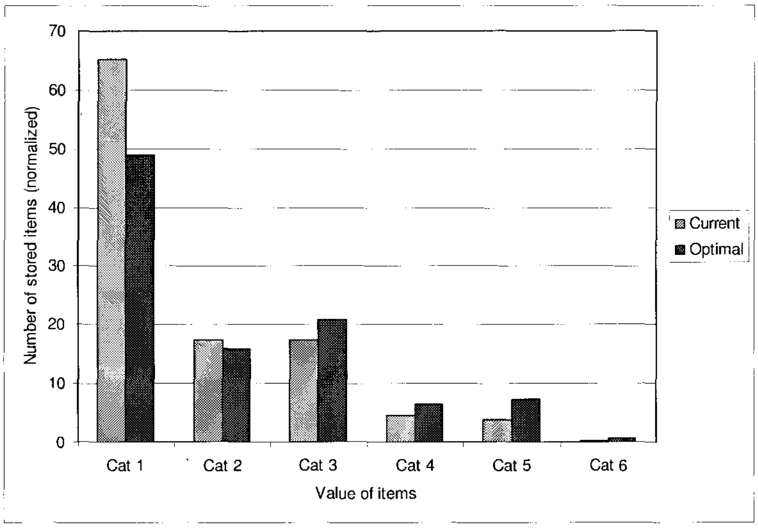


Figure 23; overview of the value of all items stored in the fieldstock

As can be seen in Figure 23, the optimisation program advises to store more high-value items compared to the current configuration. This is a somewhat surprising result, because it was expected that the optimisation program would store less expensive service parts in the fieldstock compared to the current configuration. However, due to the relatively high urgent order costs, it is still worthwhile to store these high-value parts in the fieldstock.

Because the program advises a larger investment in fieldstock items, the risk of obsolescence will increase compared to the current configuration. However, there are a few reasons that this increase in risk of obsolescence will be limited:

- The total savings that can be achieved by the program most probably outweigh the costs required for EOS-management.
- Although the total investment in items increases, the total number of items slightly decreases. This means that the EOS-management needs to be applied for fewer items in the fieldstock.
- Most service parts in the fieldstock are fast moving service parts. The risk of obsolescence for these parts is lower than for slow moving service parts.

8.2.3. Location characteristics

This subsection describes the location where the service parts need to be stored according to the program, and thereby shows how the program uses the characteristics of the service parts to determine the storage location.

For both configurations, the value of the items stored in the QRS is higher than the value of the items in the carstocks. This is because the storage costs for the QRS are higher than the storage costs for the carstock. Furthermore, the lateral transhipment costs are taken into account for a transport from the QRS to a carstock. Figure 24 gives an overview of the demand and value per service part, and the storage location for these parts.

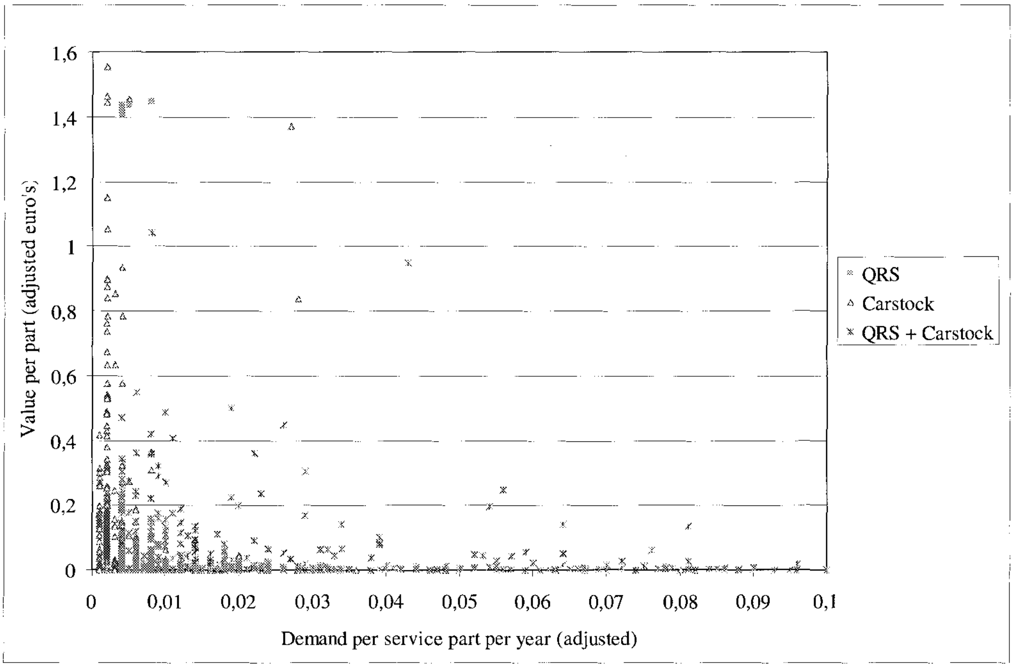


Figure 24; characteristics of the service parts, and the advised storage location for CC Ost

As Figure 24 shows, a large portion of the service parts (39%) are stored in the QRS as well as in the carstock. The reason for this is that the program uses the QRS as an 'overflow' location, to avoid stock outs of the carstocks. Therefore, also low value parts are stored in the QRS. 60% of the service parts is only stored in the carstock. Six parts are advised to be stored in the QRS, and not in the carstocks. These parts can be observed in the upper left corner of the figure. Four parts do not have to be stored in the fieldstock. These four parts belong to a DG-machine, and have a high value and low demand.

A somewhat surprising effect is that 60% of the service parts with a low demand and a high value have to be stored in the carstock, and not in the QRS. It was expected that these parts had to be stored in the QRS.

However, 92% of these parts are demanded at only one carstock, making it inefficient to store these parts in the QRS. Storing these parts in the QRS would result in an unnecessary lateral transhipment. If the demand would have occurred at multiple carstocks, these parts have to be stored in the QRS. To prove this, Figure 25 shows the advised location per service part with the assumption that the demand is symmetrical. Symmetrical demand means that all carstocks generate the same demand.

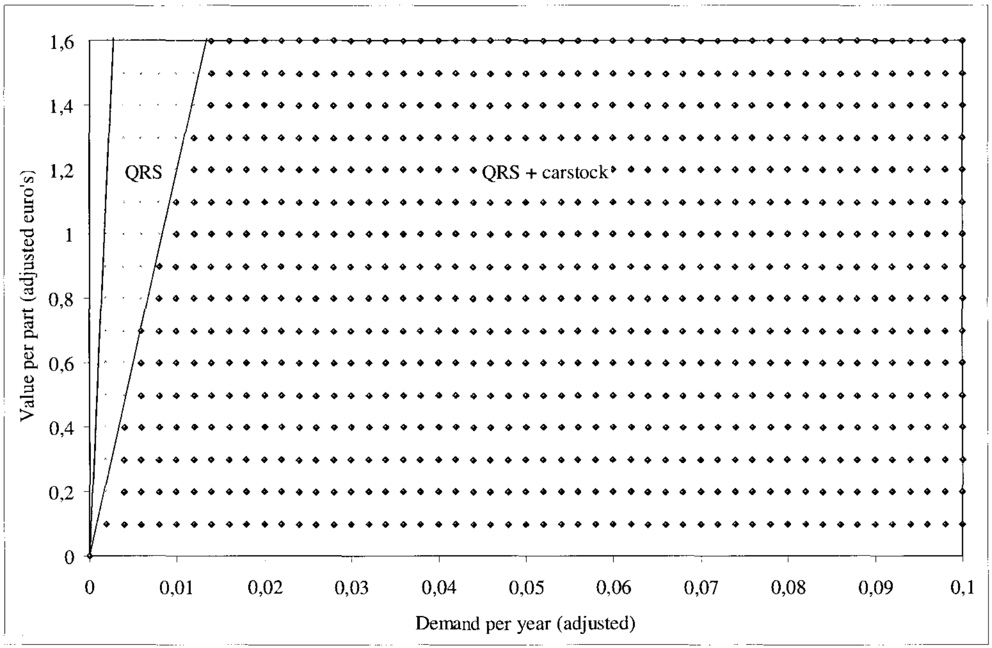


Figure 25; conceptual overview of the optimal location with the assumption of symmetrical demand

As can be seen in Figure 25, symmetrical demand results in clear criteria for the storage location of service parts. When forecasting demand in a real-life situation, the forecasted demand per service part will be spread out over multiple carstocks. This results in an advice that low-demand, high value parts have to be stored in the QRS instead of one carstock. Because the forecasted demand per carstock is not perfectly symmetrical either, the output of the optimisation program based on forecasted demand will be a mix of Figure 24 and Figure 25.

8.2.4. Machine groups

For all previous analyses in this chapter it was assumed that the target first visit fill rate had to be met for each carstock. Although the first visit fill rate was high for all carstocks, it may happen that for individual machines the target first visit fill rate is not met. Therefore, this subsection describes the performance for different machine groups.

Most technicians only repair DDS-machines or only WFPS-machines. Of the 32 technicians of CC Ost, 23 technicians repair DDS-machines, and nine repair WFPS-machines. It was observed that the target first visit fill rate and the cost optimal configuration was achieved for all technicians. No differences can be observed between the two business units.

One WFPS-technician within CC Ost also repairs DG-machines. The service parts of the DG-machines have a high value compared to the other service parts. Although the first visit fill rate for this technician was equal to 0,98, the mean first visit fill rate for the DG-service parts was equal to 0,36. Therefore, two demand groups were created for this technician; a group for the demand occurring for DG-parts, and a demand group for service parts of other machines. A target first visit fill rate of 0,95 was set for both machine groups. After this adjustment, the target first visit fill rate was met for both groups.

As a conclusion it can be said that, although the average first visit fill rate is high, for some machines this may result in a first visit fill rate below target. Therefore, it is advised to define target first visit fill rates for different machines or group of machines. This is especially relevant for the machines with high-value service parts that require a high target first visit fill rate.

8.3. Model extensions

This section describes the effects of changes in parameters, and different fieldstock settings on the outcomes of the optimisation program model. Subsection 8.3.1 describes the effects of different lateral transhipment possibilities, Subsection 8.3.2 discusses changes in carstock size, and Subsection 8.3.3 shows the effects of a decrease in regular replenishment frequency. All analyses are based on the input parameters of CC Ost.

8.3.1. Lateral transhipment options

To analyse the effects of lateral transhipments between carstocks, two fieldstock situations are analysed; the situation with a QRS, which is in use for most OpCo's, and the situation without a QRS. The situation without QRS is used in Belgium, and for several technicians in other OpCo's for which the distance to a QRS is not within the first visit time frame.

Per basic situation, four different settings have been tested; the basic setting, three carstocks as main warehouse, nine carstocks as main warehouse, and all carstocks as main warehouse. These different settings were compared with the basic setting. The carstocks used as main warehouse were selected based on the demand for the type of machines at the carstocks. Thereby, three groups of machines were defined, whereby most technicians repair one of these groups. The first group of machines are the 31X5-machines and the Varioprints, the second group are the CPS-machines, and the third group are the TCS and TDS-machines.

Although different lateral transhipment possibilities may lead to a better performance, in reality it is not always possible to have lateral transhipments between carstocks. It may for example be the case that carstocks are too far from each other to have an efficient lateral transhipment, or that technicians do not work. The OpCo always has to make the judgement whether to have a lateral transhipment or wait for an urgent order.

For all situations, it is assumed that the lateral transhipment costs are equal for the lateral transhipments from the QRS as well as for the lateral transhipments between carstocks. In reality, lateral transhipments between carstocks may be more expensive, because the total distance that a courier has to cover is larger, or a technician spends more time on a lateral transhipment to another carstock, compared to the lateral transhipment costs from a QRS.

Fieldstock with QRS

For this analysis, the QRS is the first main warehouse that is checked for a lateral transhipment, followed by other carstocks within the same group. The overview of the performance for these settings is shown in Table 6.

Performance indicators	Number of main warehouses			
	QRS (basic)	QRS and 3 cars	QRS and 9 cars	QRS and all cars
Total relevant costs	100	136	102	83
Investment	100	99	95	88
Urgent + lateral costs	100	210	141	96
First visit fill rate	0,998	0,998	0,998	0,999

Table 6; performance overview of different lateral transhipment possibilities with QRS (normalized)

The performance of the setting with four main warehouses shows a somewhat surprising result. The total relevant costs are higher than the total relevant costs for the setting with less lateral transhipment possibilities. This is because the three main carstocks also contain parts that do not fulfil the demand for these three carstocks, but that are used for lateral transhipments to other carstocks. This results in an inventory for these three main carstocks in which 43% of the service parts is not used to fulfil demand occurring at the carstock itself, but is used for lateral transhipments. This results in an average fill rate for these carstocks of 0,87. The QRS makes sure that the target first visit fill rate is met, resulting in extra lateral transhipments. This increases the total relevant costs. This means that the optimisation program is not optimal in these cases. As said before, the program is close to optimal if the carstock size is unlimited. In this case, the carstock size limits the number of parts that needs to be stored in the main carstocks strongly. Therefore, the optimisation program is not optimal in these cases.

Using nine or all carstocks as main warehouse overcomes the increase in lateral costs. This is because the inventory required for lateral transhipments is spread out over more main carstocks instead of four. This results in higher carstock fill rates for the main carstocks, and therefore less lateral transhipments are required, resulting in lower total costs. The total costs for the setting with ten main warehouses are slightly higher than the total costs for the basic setting. The total investment in service parts is smaller than the investment for the basic setting. For the setting with all carstocks as main warehouses, the total relevant costs are lower. Remarkable for this setting is that the program only stores two service parts in the QRS. This means that the QRS is more or less useless, because of the lateral transhipments between all carstocks.

Fieldstock without QRS

For the fieldstock without QRS, the same settings were analysed as the setting with a QRS. The results of the analyses are shown in Table 7.

Performance indicators	Number of main warehouses			
	No mains	3 cars	9 cars	All cars
Total relevant costs	100	130	75	66
Investment	100	93	93	91
Urgent + lateral costs	100	155	64	49
First visit fill rate	0,993	0,990	0,998	0,999

Table 7; performance overview of different lateral transhipment possibilities without QRS (normalized)

The results in Table 7 are quite similar to the results in Table 6; three carstocks as main warehouses leads to higher total costs than the basic situation, whereas nine or more main carstocks results in lower total costs. The main reason for this is that the three main carstocks store service parts that are not used to fulfil the demand occurring at those carstocks. This effect is stronger for the situation without QRS's, because the QRS cannot be used to meet the first visit fill rate. The result of this is that two of the three main carstocks do not meet the target for the first visit fill rate.

Table 7 can also be compared with Table 6. This comparison shows that the QRS reduces total costs if no lateral transhipments, or a few lateral transhipments take place between carstocks. However, if more lateral transhipments are possible, the QRS does not lead to lower costs, and becomes useless in the case of nine main carstocks or more. However, in real-life situations at the OpCo's it may not always be possible to have lateral transhipments between carstocks.

8.3.2. Carstock size

This subsection analyses the influence of the carstock size on the total relevant costs. Increasing the carstock size may lead to a decrease in total relevant costs. Furthermore, the limited carstock size may lead to a suboptimal outcome of the optimisation program.

For each analysis, all carstocks were given the same maximum carstock size. The maximum number of items per carstock varied between 100 and an unlimited number of items per carstock. For all settings, the QRS can contain an unlimited amount of items. Figure 26 shows the consequences of changing the maximum number of items in the carstock on the total relevant costs. For the basic setting, a maximum of 250 items can be stored in each carstock. For all settings, the first visit fill rate was equal to 0,99 or higher and in all situations the cost optimal configuration was reached.

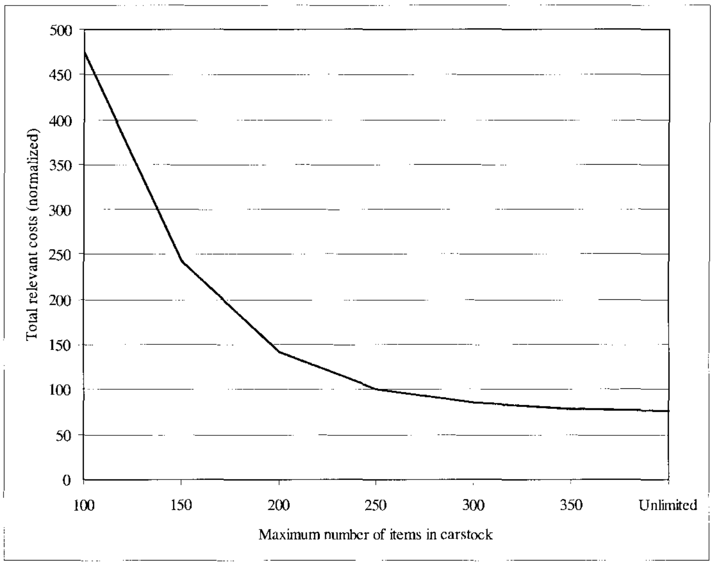


Figure 26; consequences of different maximum number of parts in the carstock

As can be seen in Figure 26, the total relevant costs decrease if the maximum number of items in a carstock is increased. An unlimited carstock size would result in a decrease of the total relevant costs of 24% compared to the basic configuration of 250 items. To find out whether it is really beneficial to use larger cars the cost savings of 24% have to be compared with the additional costs of using larger cars.

To determine the maximum carstock size, all carstocks were given the average number of currently stored items, which was equal to 250. If the actual number of items stored in each carstock is taken as maximum carstock size, this results in total relevant costs that are 10% lower than the basic configuration. This means that the maximum carstocks size of 250 parts per carstock may be a conservative estimation, and the actual carstock size is somewhat larger.

For this project, the optimisation program developed by Kranenburg (2006) was adjusted for the maximum carstock size. The maximum carstock size limits the total number of possible outcomes of the program. Therefore, it does not guarantee a cost optimal solution with regard to the service level in every case. It may be the case that the first visit fill rate is not maximised with minimal total costs. Minimal total costs can only be guaranteed if the carstock size is unlimited. However, as said before, the current carstock size results in total costs that are relatively close to the situation with unlimited carstocks size, and therefore the difference between the optimal configuration and the configuration calculated by the program is probably small.

8.3.3. Longer replenishment times

Currently, a project is being executed to reduce total logistical costs at Océ. One of the possibilities is to reduce the frequency of regular replenishments. Currently, for some OpCo's, each technician is being regularly replenished every day, if this is required. Reducing this frequency may save costs for the regular orders, but will lead to increasing costs for the fieldstock inventory. To be able to make a fair comparison, the optimisation program can be used to calculate the consequences of this frequency reduction for the fieldstock inventory. Then, a comparison can be made between the reduction in costs for the decrease in replenishment frequency and the additional costs for the fieldstock inventory.

One remark has to be made for these changing frequencies; the reliability of the outcomes of the optimisation program decreases if the replenishment frequency is reduced. Reducing the replenishment frequency increases the replenishment lead-time. The replenishment lead-time consists of two elements. The first element is the time that a technician can order a part. The second time element is the time between the cut-off time and the time that the part arrives in the fieldstock. If the replenishment frequency is decreased, the total order time becomes larger. This results in larger differences between individual orders, because the orders are spread out over a larger time period. This makes the estimation of the regular replenishment time less reliable. This is also shown in Figure 27.

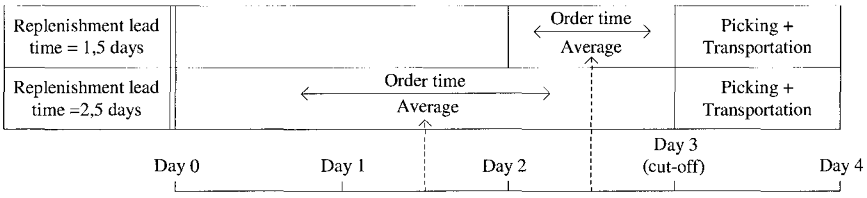


Figure 27; consequences of an increasing total lead time

Figure 28 shows the consequences of changing the regular replenishment lead-time for the investment in service parts and for the total relevant costs. The lead times used for this analysis are the average replenishment lead times, which are also shown in Figure 27. In this figure the average replenishment lead-time is equal to 1,5 days for the upper situation, and 2,5 days for the lower situation. The costs and investments in Figure 28 are normalized in order to be able to compare the changes in investment with the changes in total relevant costs.

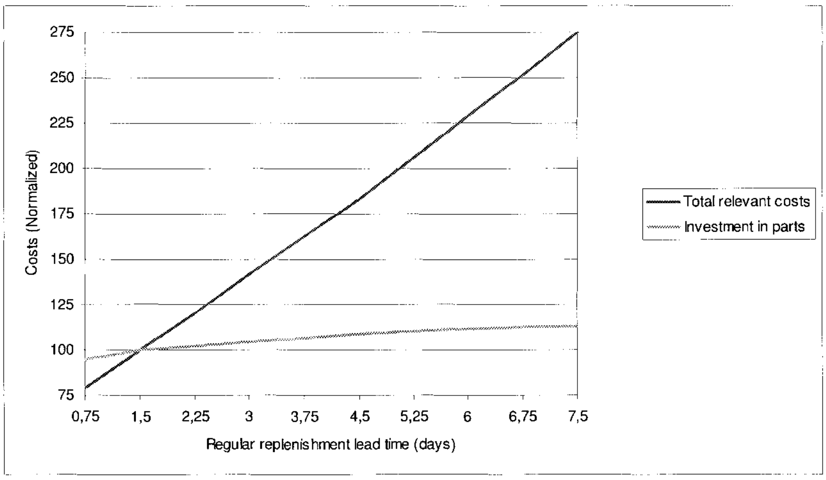


Figure 28; overview of the costs of changing regular replenishment lead time (basic optimal situation = 100)

Figure 28 shows that the total relevant costs are sensitive to changes in the regular replenishment lead-time. For example, changing the regular replenishment lead-time from 1,5 days (the currently used lead time for CC Ost) to 3 days leads to an increase of the total relevant costs of 42%. The increase in investment in parts is less sensitive to changes, because the maximum carstock size limits the number of service parts that can be stored in the carstock. This results in a larger investment in service parts in the QRS, and thus to an increase of the lateral transhipment costs. This is also the main reason for the increasing total relevant costs. The first visit fill rates are larger than 0,99 for all configurations.

When comparing the results of an unlimited carstock size with the results of a limited carstocks size, it can be seen that the influence of the limited carstock size on the total relevant costs is large. The increase in total relevant costs is equal to 36% if the regular replenishment time is increased from 1,5 days to 7,5 days, for the unlimited carstock setting. With the limited carstock size, this increase is equal to 175%. The higher investment in parts results in less lateral transhipments and urgent orders, and thus in lower total relevant costs, compared to the case with limited carstock size.

As a conclusion, it can be said that when Océ wants to increase the regular replenishment lead time, the extra costs required for the fieldstock management have to be weighted against the costs savings decrease in regular replenishment frequency. Because the maximum carstock size has a large influence on the relevant costs, it may be wise to increase the carstock size if the regular replenishment frequency is decreased.

8.4. Sensitivity analysis

To analyse how the outcomes of the optimisation program change if the input parameters change, a sensitivity analysis is executed. Subsection 8.4.1 describes the sensitivity of the order costs, and Subsection 8.4.2 discusses the sensitivity of the costs related to inventory.

8.4.1. Order costs

As said before, the costs related to urgent orders and lateral transhipments have a large impact on the results of the model. This is because the urgent order costs are large compared to the costs of inventory keeping. Estimating the urgent order costs is hard, because it is mainly based on the time a technician needs to make a second visit. Therefore, this section analyses the sensitivity of the outcomes of the model with regard to changing urgent order costs. This makes it possible to estimate the effects of a wrong estimation of these costs.

A restriction for this analysis is that the urgent order costs must be larger than the lateral transhipment costs. If this is not the case, the program will exclude the QRS as possibility for storage because it is too expensive to store parts in the QRS. Therefore, this analysis was executed with different combinations of urgent order costs and lateral transhipment costs, whereby the urgent order costs are larger than the lateral transhipment costs for all combinations. Figure 29 shows the results of this analysis. The costs are normalized in such a way that the basic urgent orders costs are equal to 100, and the lateral costs and other urgent order costs are based on this basic value. Thus, if the lateral order costs are equal to 40, this means that these costs are 40% of the basic urgent order costs.

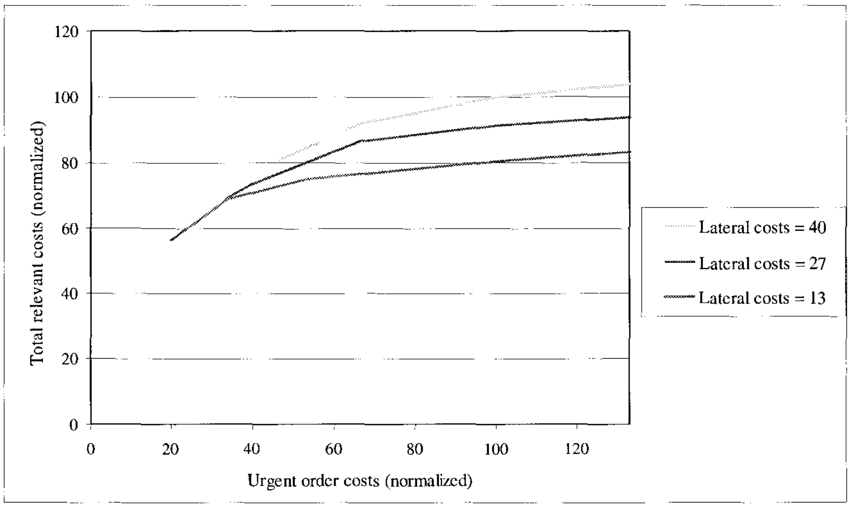


Figure 29; changes in the outcomes of the program for different urgent order costs

As can be seen in Figure 29, the total relevant costs are relatively insensitive for changes in the urgent order costs, as long as the difference between urgent order costs and lateral transhipment costs is relatively large. If the difference gets smaller, the sensitivity increases. For the setting with lateral costs equal to 67, the total costs decrease 8,1% if the urgent order costs change from 133 to 67. However, if the urgent order costs are decreased from 67 to 33, the total costs decrease 20,3%. The main reason for this is that it becomes more expensive to store parts in the QRS, and therefore the storage costs decrease.

For the basic configuration, it was estimated that the urgent order costs are equal to 100, and the costs for a lateral transhipment are estimated to be 40. Figure 29 shows that the sensitivity of the program is relatively small around 100. If, in reality, the urgent orders costs are equal to € 100 the total relevant costs are 3,8% higher than calculated by the program. If the urgent orders costs would be equal to 67, the total relevant costs are 8,3% lower than the basic situation.

Because it is not expected that the urgent order costs are lower than 67, it can be concluded that the program is quite insensitive with regard to changes in the urgent order costs.

8.4.2. Inventory costs

The previous subsection describes the sensitivity with regard to the urgent and lateral order costs. With regard to the costs related to inventory keeping, two cost factors are relevant; holding costs and storage costs. The sensitivity of these costs is analysed in this subsection.

An increase in holding costs means that it is more expensive to keep inventory compared to the costs for lateral and urgent orders. This results in more lateral transhipments and urgent orders, and a lower investment in parts. The total relevant costs increase when increasing the holding costs in a nearly linear way. As a general rule, it can be said that a change of the holding costs of 10% leads to a change of the total costs of 5%. The fill rates are high in all relevant cases, and the investment in service parts is insensitive with regard to an increase in holding costs. Increasing the holding costs from 8% to 12% leads to an investment that is 6,5% lower.

The storage costs are currently only used for items that are stored in the QRS. For the carstocks no storage costs are used, because the technicians use their car anyway. If storage costs are introduced for the carstocks as well, this results in less service parts to be stored in the carstock, and more parts in the QRS. In total, inventory keeping becomes more expensive, and therefore less service parts are advised to be stored in the fieldstock. This results in increasing total relevant costs.

8.5. Second case study

To analyse whether the savings achieved in Section 8.1 can also be achieved for other regions, this section analyses the performance of the program in another region. For this analysis CC Nord of OpCo Germany is taken. Because this CC includes three QRS's it is also possible to analyse whether it is beneficial to have lateral transhipments between the QRS's. Therefore, the column 'no lateral between QRS's' shows the performance of the optimisation program without lateral transhipments between the QRS's, and the column 'lateral between

QRS's' shows the performance if lateral transhipments between QRS's are possible. In reality, it may not be possible to have lateral transhipments between these QRS's, due to a large distance.

	Current configuration	No lateral between QRS 's	Lateral between QRS's
Average fill rate from car	0,708	0,989	0,987
Average first visit fill rate	0,765	0,996	0,998
Investment in service parts	100	146	143
Total relevant costs	100	10,9	10,9

Table 8; performance overview of CC Nord (normalized)

Table 8 shows similar results as the comparisons made in Section 8.1 for CC Ost. In this case, the total relevant costs given by the optimisation program are 11% of the total relevant costs currently incurred at CC Nord. Similar to CC Ost this can be achieved by an investment that is higher than the current investment in service parts. The setting with the lateral transhipments between the three QRS's does not lead to a significant decrease in total costs.

It is expected that the other four CC's for OpCo Germany show similar results. In the second chapter it was stated that OpCo Germany is one of the best performing OpCo's. Therefore, the results for other OpCo's may result in a larger improvement of the performance of the fieldstock. Due to time restrictions and data availability it was not possible to compare the actual performance of these OpCo's with the performance of the optimisation program.

9. Implementation plan

This chapter describes how the optimisation program should be implemented within Océ. Section 9.1 describes how support for the program was and will be created. Sections 9.2 and 9.3 discuss how the implementation at the OpCo's and LSP should take place. To fully implement the program, it is also required to have a structured method to obtain the input for the program. This is described in Section 9.4. Finally, a description of the day-to-day usage at the OpCo's is given in Section 9.5.

9.1. Support for optimisation program

To implement the optimisation program, it is required that there is support for the program and willingness to use the program within Océ. During the project, several actions were executed to gain support for the program. Interviews with logistics managers, field service managers, and technicians of the selected OpCo's were executed. By having these interviews, the stakeholders were able to express their needs and their opinion on the program. Furthermore, several meetings were held with service managers of the business units. To create more support for the program and the implementation, the following actions should be taken;

- An important step is to show that the optimisation program really improves the performance of the fieldstock inventory. The main goal of the business units and the OpCo's is to keep the service levels on a high level. The results mentioned in this report show that high service levels lead to a minimal cost configuration, and therefore it is in the interest for the OpCo's to use the program.
- If the problems and complaints of the current carstock IT-system are taken into account for the implementation this will increase the support for the optimisation program. The required time to generate output should be small, and preferably smaller than the time required to use the current carstock model. This mainly depends on the implementation of the program within the IT-systems. However, one of the advantages of the program is that it can be used to optimise the fieldstock for an entire region at once. The calculation itself takes around two to three hours for 33 locations and 2400 parts. The carstockmodel requires a recalculation for every technician.
- Users must be able to understand the results of the program. This means that it is not required that they understand every detail of the program, but they must be able to intuitively understand the results. Therefore, a document should be written that contains the important characteristics of the program, and describes how the program responds to changing parameters. Starting point for that document is this graduation report. Furthermore, key users should be educated to work with the optimisation program, and understand the program to a certain extent.
- Preferably, the program should be used for the service parts distributed from the RSC in Venlo, as well as for the continuous feed service parts distributed from Poing. This will increase the support for the program, because it simplifies the total service parts management. One of the main complaints of the OpCo's with regard to service parts management is that there are two separated supply chains.

9.2. OpCo implementation

To implement the optimisation program at the OpCo's, three phases need to be distinguished;

Phase 1

For this phase, a pilot project in one region needs to take place. The main purpose of the pilot is to find out what savings can be achieved by the program in real-life. Therefore, it is not required to have a full system implementation. Another activity for this phase is to find out what improvements are needed with regard to the current carstock IT-systems and demand forecasts. These improvements can be taken into account for the full implementation in the following phases.

Phase 2

During this phase, it is required to determine how the program performs in the test-region and whether adjustments to the program are required. Based on the findings for the required improvements of the IT-systems, and the implementation of the optimisation program into the IT-systems, an estimation can be made about the changes that are required. This phase also shows the total costs of implementation and the actual benefits of the optimisation program. Based on the required changes in the IT-systems, a design can be made for the full implementation into the system.

Phase 3

This phase includes the full implementation in the IT-systems, followed by an implementation in one OpCo. It can be evaluated whether the program is implemented and performing as it should. If the implementation is successful, a roll-out in all DR-OpCo's can take place. This also requires the education of key users, defining procedures, and data collection, etc. A rough estimation is that the full implementation of the program into the

IT-systems costs around € 300.000, based on capacity required for planning, building, programming and testing of the program. It is expected that this investment can be earned back within one year. The total cost savings shown for the two case studies executed in Chapter 8 are almost equal to € 800.000 per year.

9.3. LSP Implementation

Within LSP, the subdepartment of Supply Chain Management (SCM) should be responsible for the program. This new subdepartment is responsible for service parts supply chain management, and does not only focus on the inventory costs, but takes all supply chain costs into account. To do this, SCM co-operates with subdepartment IC, which is responsible for the fieldstock inventories of DR3-OpCo's.

For the DR3-OpCo's, it is recommended that SCM is able to adjust certain parameters of the program. This concerns the parameters that can be determined by SCM, such as the costs, service part data, and target fill rates. The OpCo's should estimate parameters about warehouses and demand forecasts for technicians, because they have knowledge about the local situation. Furthermore, for the DR3-OpCo's, SCM should be able to review the advices of the program, and compare the fieldstock inventory with the advices given by the program. To evaluate the fieldstock inventory of OpCo's, the evaluation program can be used.

For SCM, there are two reasons to use the program;

- SCM can use the program to calculate the consequences of tactical decisions on the fieldstock. This includes decisions about service levels, replenishment lead times, etc.
- Furthermore, the program may be used to evaluate the OpCo's performance. Therefore, an adjusted program has been built. This program evaluates current fieldstock configurations.

9.4. Data collection

As said before, a good estimation of the input parameters is essential for a good performance of the optimisation program. Thereby it is important that data are collected at the level of the organisation that is able to estimate the parameters, and has knowledge about these data. The required input parameters can be divided in five categories.

Service parts data

The data about the service parts consist of the service part ID, service part description and the value of the service part. It is relatively easy to gather these data. The value of the parts depends on the type of OpCo where the program is used. For DR3-OpCo's the standard price needs to be used, whereas for the other OpCo's, the ICP has to be used. It is advised to limit the total amount of service parts in the program, because this requires more calculation time. Therefore, it is best to use only parts for which demand is expected.

Warehouse data

The warehouse data describes the amount of warehouses within one region, the names of the warehouses, the maximum number of parts that can be stored in each warehouse, and the possibilities of lateral transhipments between the warehouses. Thereby, all warehouses that are connected to each other have to be optimised simultaneously. The maximum number of parts that can be stored in the carstock can be estimated by looking at the current number of parts in each carstock. The OpCo needs to collect the warehouse data.

Target fill rates

One of the main results of the optimisation program was that the fill rates achieved by the program are quite high in general. However, for machines with high value service parts with a low demand, these first visit fill rates can be low. Therefore, it is wise to determine a target first visit fill rate for each machine or group of machines. The business units need to determine these target fill rates. Determining the target fill rates also makes it possible to evaluate the performance of the supply chain with regard to different machines and groups of machines.

Cost data

The relevant cost data are the hardest parameters to estimate, because these are partly based on assumptions. There are three sorts of costs relevant for the program:

- Costs with regard to inventory keeping, for which two input parameters are required:
    - Holding costs. These costs are represented as a percentage of the value of the parts, and are equal for all locations. For this, it is required to use the holding costs used at Océ to estimate the costs of inventory keeping. In general, the holding costs are equal for all OpCo's.
    - Storage costs. This parameter depends on the service part and on the location where the part is stored, and is harder to estimate. For the QRS's, the storage costs can be estimated by using the tariffs related to the QRS. A good estimation is to divide the total renting costs per year by the number of parts stored in the QRS. It is wise to update this parameter every year.

- Costs of lateral transhipments. These costs can be estimated by using the tariffs used at the QRS, because a logistics service provider takes care of these transhipments. This parameter should also be updated once a year.
- Costs of urgent orders. As said before, this parameter has a large influence on the program. The urgent order costs mainly depend on the technician costs. This parameter can be estimated by calculating the costs of a technician making a second visit, and thus depends on the technician costs and time required for a second visit. This parameter needs to be updated every year as well.

Forecast of the demand per technician

Besides the cost data, the forecasted demand is also a parameter that is hard to estimate. Currently, the following procedure is used in most OpCo's; The total demand per service part over the past six months or one year is taken, and divided by the installed base in order to calculate the failure rate per service part. Next, an estimation per technician is made on the type of machines and the amount of machines the technician will repair in the coming year. By using the failure rate per part, an estimation can be made of the demand per technician in the coming period.

For large OpCo's this may result in relatively reliable forecasts, but for the smaller OpCo's, this leads to unreliable estimations of the failure rates. Therefore, it would be good to estimate failure rates by using the data of multiple OpCo's. LSP should help the OpCo's with the estimation of these forecasts. After the introduction of DR3 in more OpCo's, this can be done more easily, because the demand data for service parts can be combined with installed base data.

This requires reliable information about the installed base, and the bill of materials of machines. Currently, no reliable data are available at LSP, and therefore a structured method to calculate the failure rates needs to be developed. In order to keep the program adjusted to the current situation, the optimisation program needs to be executed on a regular basis. Thereby, it is suggested to update the demand data every six months. Forecasted demand data rapidly change, due to the introduction of new machines and changing market conditions.

9.5. Usage of the program

As was described in the previous section, it is required to run the program every six months for each region. This requires the following procedure;

- Run the program for the first time, and send the advised basestock levels to the FSM and technician.
- The FSM and technician probably want to make adjustments to the basestock levels generated by the program. If they do so, they have to send the list with adjusted basestock levels back to the program user. The program user uses the adjusted basestock lists from all technicians as input for the evaluation program. The evaluation program then calculates the performance of the adjusted system, and it can be evaluated whether the adjusted basestock levels meet the target first visit fill rate.
- If the target first visit fill rate is met, the adjusted basestock levels can be used. Otherwise, new adjustments need to be made, until the target first visit fill rate is met. This can be done by adding service parts to the QRS.

10. Conclusions and recommendations

This chapter concludes this thesis by describing the most important conclusions and recommendations.

10.1. Conclusions

The main stakeholders within Océ feel that the fieldstock inventory of service parts is unbalanced, and therefore the following research assignment was defined:

Analyse whether the fieldstock inventory of service parts of Océ is unbalanced and whether this is caused by unclear fieldstock guidelines or by other factors mentioned in the problem cluster.

After an analysis of the current fieldstock inventory of four OpCo's it was concluded that it seems that the current investment in inventory is unbalanced with regard to the required service levels. An analysis of the inventory management revealed that the unbalanced investment is caused by fieldstock guidelines that do not optimise the entire fieldstock, but only focus on the carstock inventory as a single echelon inventory point. This makes it impossible to optimise the fieldstock configuration with regard to a target service level and all relevant costs. To overcome this, the following design assignment was formulated;

Design a model to overcome the unbalanced investment in fieldstock inventory. This model should optimise the inventory in the fieldstock with regard to all relevant costs and a target service level. The model must be adjustable by OpCo's to a certain extent. Therefore, an implementation plan should specify how to implement the model.

To execute this assignment, an optimisation program was developed that is based on a multi-location model developed by Kranenburg (2006). This program calculates basestock levels for all fieldstock locations and service parts in order to minimise total relevant costs with regard to a target first visit fill rate. The first visit fill rate is used because it is the best way to measure the performance of the service parts supply chain.

The optimisation program has been used to compare the current performance with the performance calculated by the program. For the region that was used as case study, the program gives a fieldstock configuration that achieves the same first visit fill rate with an investment that is 67% lower compared to the current investment in service parts. However, more savings can be achieved with a higher investment in service parts than the current investment. This configuration leads to total relevant that are 93% lower than the current costs. Another case study leads to a reduction of 89% of the total costs.

The program shows that costs related to urgent orders have a large influence on the outcomes of the program. This is because the total inventory costs are small compared to the urgent order costs and lateral transhipment costs. This means that a high first visit fill rate is achieved with low total costs. However, for machines with high-value service parts the first visit fill rate is not always met. Therefore, it is required to set a specific target first visit fill rate, to avoid a low first visit fill rate.

Different configurations and fieldstock settings have been analysed. The main results of these analyses are:

- In most cases, lateral transhipments between carstocks do not improve the performance. This is caused by the limited carstock size that does not allow storing all required parts in the carstocks. Although some settings decrease the total costs, it is questionable whether these settings are realistic.
- Increasing the carstock size leads to somewhat lower total relevant costs, but it is questionable whether this outweighs the costs of larger cars.
- Decreasing the regular replenishment frequency leads to a large increase of the total relevant costs. The main cause for this is that the limited carstock size results in more lateral transhipments. Therefore, it may be wise to use larger cars if the replenishment frequency is decreased.
- The program is relatively insensitive for changes in urgent order costs within the relevant range.

Besides a better performance of the optimisation program compared to the current situation, there are other advantages related to the program:

- The OpCo's did not have a tool to optimise the QRS inventories. This program overcomes this issue.
- The program makes it possible to calculate the effects of changing parameters. If changes in the supply chain need to be made, the program can calculate the consequences of these changes.
- The program makes it possible to set different target service levels for different machine groups.
- The evaluation program makes it possible to make a fair benchmark analysis of OpCo's.

10.2. Recommendations

The conclusions of the previous section lead to the following recommendations:

- Using the optimisation program improves the performance of the service parts supply chain. Therefore, it is recommended to use the optimisation program to manage the fieldstock. It is expected that the implementation costs can be earned back within one year.
- To evaluate the performance of LSP, the RSC and the OpCo's in a customer oriented manner, a more differentiated approach towards service should be applied. This means that for each machine or group of machines a specific target service level should be set. Currently, all machines have the same target service level, and the service level is measured over all machines together.
- Currently, no 'DR3 performance targets' have been set. The RSC measures its performance, and the OpCo's measure their performance at the customer, but no performance indicators for the entire supply chain are used. This includes performance indicators about service levels at the final customer, and total costs over the entire supply chain. The evaluation program can be used to evaluate the performance of different fieldstocks configurations.
- Important issues with regard to the implementation of the optimisation program are:
    - Support for the program can be increased if the IT-systems are adjusted in such a way that the program is easy to use, and if most stakeholders are convinced that the program improves fieldstock management. All stakeholders need to understand the main concepts behind the program.
    - Data used as input for the program should be gathered at those units of the organisation that have knowledge about these data and that have responsibility for these data. This results in the best estimations for these data.
    - Demand forecasts are important for a correct use of the program. The current methods seem to be accurate, but are time consuming to execute. Therefore, it is wise to review these methods, and analyse whether improvements are necessary.
    - Within LSP, the subdepartment of SCM should be responsible for the program. SCM should give support with regard to the program, and can use the evaluation program to evaluate OpCo's.

For the correct use of the program, some organisational issues are relevant as well:

- The program has a total cost approach, and shows that the lateral and urgent order costs strongly influence the performance of the fieldstock. Therefore, it is important to have a clear overview over all relevant costs of the supply chain within the same organisational unit. Currently, costs are incurred at different units of the organisation, resulting in a suboptimal cost approach. Therefore, it is recommended that all costs with regard to DR3-fieldstocks should be incurred at LSP. When this cost structure is known, decisions can be taken based on all relevant costs. Furthermore, this makes it possible to evaluate the performance of LSP with regard to all relevant costs, and not just the inventory costs.
- Within the DR3-concept, there is no clear overview of the responsibilities of the OpCo's and LSP. No clear procedures are defined for the management of service parts within the fieldstock. For example, if LSP wants to return service parts from an OpCo to the RSC, it is not clear what influence an OpCo has on this decision. Furthermore, if an OpCo wants to store extra parts, it is not known whether LSP has to agree. The optimisation program should help with these decisions, because it gives a better overview of the parts to be stored. However, it is still required to define procedures in which the responsibilities over the fieldstock are described.

References

Aken JE van, Bij JD van der & Berends JJ (2003); Collegedictaat Bedrijfskundige Methodologie; *Dictaat TU/e*, Eindhoven.

Alfredsson P, Verrijdt J (1999), Modelling emergency supply flexibility in a two-echelon inventory system. *Management Science*; 45, 10, pp 1461-1431.

Annual Report Océ NV (2006).

Botter R & Fortuin L (2000); Stocking strategy for service parts - a case study; International Journal of Operations & Production Management, Vol. 20, No. 6, pp. 656-674.

Breure A (2007); Autovoorraden bij Nashuatec services Benelux. Master Thesis, Eindhoven University of Technology (*in Dutch).*

Caggiano KE, Jackson PL, Muckstadt JA, Rappold JA (2007), Optimising service parts inventory in a multi-echelon, multi-item supply chain with time-based customer service level agreements. *Operations Research*, Vol. 55, No. 2, pp 303-318.

Corbijn van Willenswaard P (2006); Multi-item, multi-location stock control for the service parts provisioning of DAF Trucks NV. *Master Thesis*, Eindhoven University of Technology.

Kranenburg AA (2006); Spare parts Inventory Control under System Availability constraints. *PhD thesis*, Eindhoven University of Technology.

Montgomery DC, Runger GC (1999); Applied statistics and probability for engineers, second edition, John Wiley & Sons.

Presentation tactical plan LSP 2007-2010.

Radder N (2004); Optimaliseren van bestelgroottes in de service parts supply chain van Océ; *Master Thesis*, Eindhoven University of Technology *(in Dutch).*

Senden W (2002); Stochastische processen 2 voor Bedrijfskunde (2s880) deel 1; Wachtrijen (*Lecture notes).* Eindhoven University of Technology (*in Dutch).*

Silver EA, Pyke DF, Peterson R (1998); Inventory management and production planning and scheduling, third edition, John Wiley & Sons.

Sommeren RJM van (2007); Spare parts inventory control for a single-echelon, multi-location model with lateral transhipments. *Master thesis*, Eindhoven University of Technology.

Strien, PJ van (1975); Naar een methodologie van het praktijkdenken in de sociale wetenschappen. *Nederlands tijdschrift voor de Psychologie* 30: 601-619.

Teunter RH, Klein Haneveld WK (2002); Inventory control of service parts in the final phase: A central depot and repair kits. *European Journal of Operational Research.* Vol. 138, pp 76-86.

Teunter RH (2006); The multiple-job repair kit problem. *European Journal of Operational Research.* Vol. 175, pp 1103-1116.

List of variables

Input variables

J	Set of fieldstock locations, with $j = 1,...,\|J\|$.
$K(\subseteq J)$	Subset of main local warehouses, with $k = 1,...,\|K\|$.
k_j	The first main that is checked for the demanded service part, if regular *j* does not have the part in stock.
I	Set of parts, where $i = 1,...,\|I\|$.
b_i	Batch size for service part *i*.
t^{reg}	Required time for a regular replenishment, with t^{reg} in days.
N	Set of demand streams, with $n = 1,...,\|N\|$.
$N_j(\subseteq N)$	Subset of demand streams that is assigned to regular warehouse *j*.
$ym_{i,n}$	Demand rate for part *i*, belonging to demand stream *n*, per year.
$S_j^{\max}$	Maximum total basestock level of fieldstock location *j*, with $j \in J \setminus K$.
$C_{j,k}^{lat}$	Costs for a lateral transhipment from main *k* to regular *j*.
C^{ur}	The additional cost for one urgent shipment compared to a normal replenishment.
β_n^{obj}	Target for the fraction of the demand that can be delivered by the fieldstock upon request within the time frame of a first visit for demand stream *n*.
TT	Number of days that technicians work per year.
TQ	Number of days that a QRS is open.
SP_i	Standard price for service part *i*.
h	Holding costs for a service part per year, expressed as a percentage of SP_i.
$C_{i,j}^{s}$	Costs of storing service part *i* at fieldstock location *j*.
$\sigma(k)$	Vector showing the pre-specified order in which main local warehouses are checked for service parts.

Intermediate variables

S_i	Vector of the basestock levels for service part *i*.
$m_{i,n}$	Demand rate for service part *i*, belonging to demand stream *n*, per day.
M_n	Total demand rate for demand stream *n*.
$M_{i,j}$	Total demand rate for service part *i* at carstock *j*.
$C_{i,j}^{h}$	Total inventory costs for service part *i* at fieldstock location *j*.
$\beta_{i,j}$	Fraction of the demand for service part *i* at fieldstock location *j* that is delivered immediately upon request.
$\alpha_{i,j,k}$	Fraction of the demand for service part *i* at regular *j* that is delivered from main *k* by a lateral transhipment.
$A_{i,j}$	Total fraction of the demand for service part *i* at fieldstock location *j* that is delivered by lateral transhipment.
$\theta_{i,j}$	Fraction of the demand for service part *i* at fieldstock location *j* that is delivered from the RSC as an urgent shipment.
$\tilde{M}_{i,k}$	Total demand for service part *i* at main *k*.
$\theta_{i,k}$	Fraction of the demand for service part *i* occurring at main *k* that is delivered by the RSC.
$\beta_{i,k}$	Fraction of the demand for service part *i* that can be delivered by QRS *k*.
e_j	Row vector of size *J* with the *j*-th element equal to 1, and all other elements equal to 0.
$\Delta C(i,j)$	Cost difference if the basestock level for service part *i* at fieldstock location *j* would be increased by one.

$\Delta W(i',j')$	The decrease in distance to the set of feasible policies if for service part *i* and fieldstock location *j*, the basestock level $S_{i',j'}$ would be increased by one.
$R(i, j)$	The ratio that calculates the increase in fill rate divided by the extra costs.
$\hat{M}_{i,k}$	The demand rate for service part *i* at main warehouse $k \in K$ including all demand from other fieldstock locations.
$\hat{M}_{i,\tilde{k},k}$	The demand rate for service part *i* with which QRS $\tilde{k}$ requests a lateral transhipment from main warehouse *k*.

Output variables

$S_{i,j}$	Basestock level of service part *i* in fieldstock location *j*, with $S_{i,j} (\in \mathrm{N}_0 = \mathrm{N} \cup \{0\})$.
$\beta_{i,j}^{total}$	Fraction of the demand for service part *i* at carstock *j* that is delivered within the time frame of a first visit.
C_i	Total expected relevant costs for service part *i* per year.

List of abbreviations

APW	Asian Pacific Warehouse
CC	Competence Centre
CML	Centrally Managed Logistics
CS&S	Customer Service and Support
CSC	Corporate Supply Centre
DDS	Digital Document Systems
DIKO	Diagnostic Kits
DR	Direct Replenishment
DG	Display Graphics
EOI	Expense On Issue
EOS	End Of Service
FSM	Field Service Manager
HQ	Headquarters
IC	Inventory Control
ICP	Inter Company Price
LSP	Logistics Service Parts
M&L	Manufacturing and Logistics
MPP	Mid Period Population
NWH	National WareHouse
OpCo	Operating Company
OTC	Order To Cash
QRS	Quick Response Stock
R&D	Research and Development
RSC	Regional Supply Centre
RRR	Rent, Room, Risk-factor
SCM	department of Supply Chain Management
TDS	Technical Document Systems
WFPS	Wide Format Printing Systems

Appendix A; Organisational structure Océ

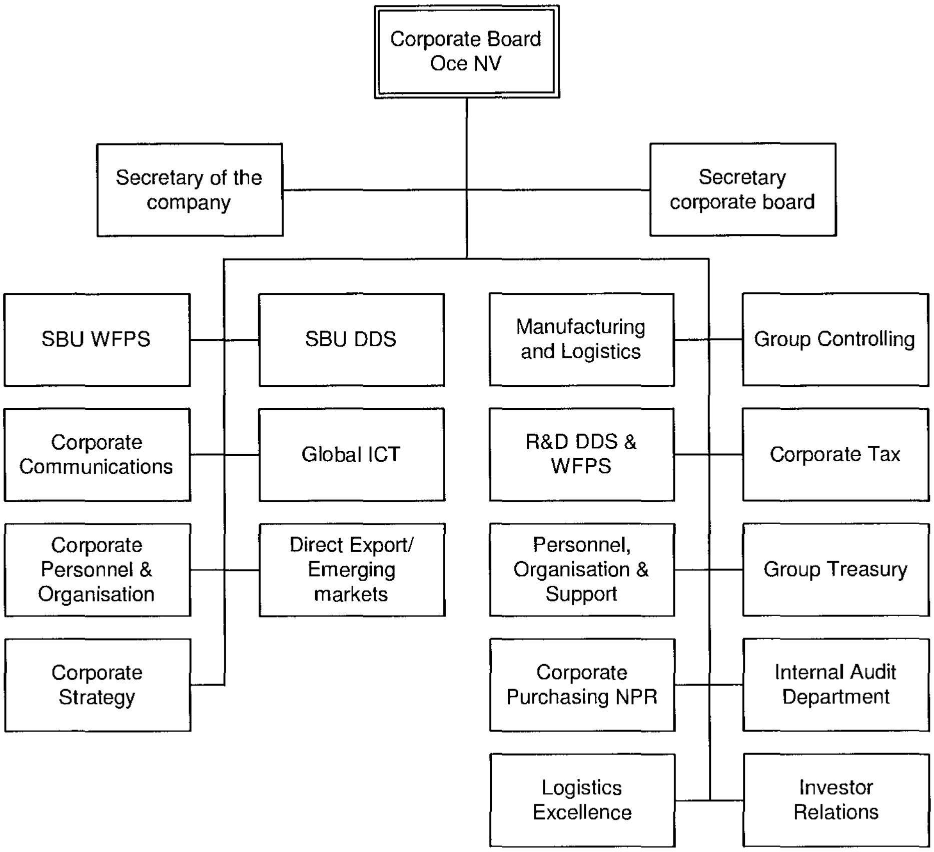


Figure 30; Organisational structure Océ NV (Intranet Océ)

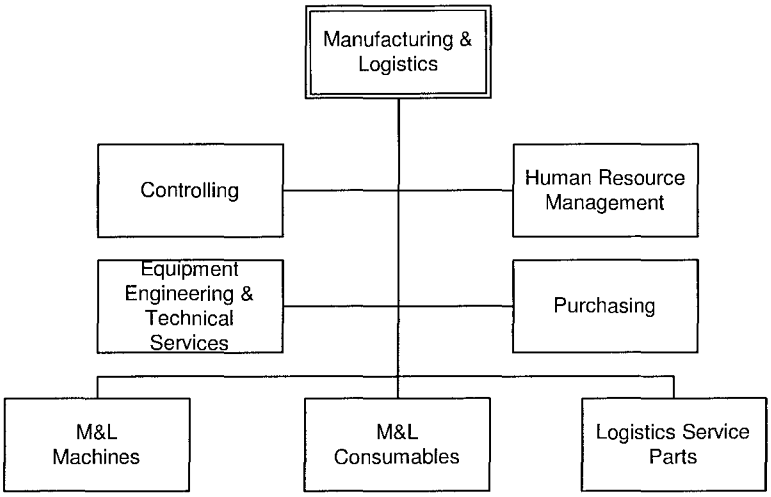


Figure 31; Organisational structure Manufacturing & Logistics (Intranet Océ)

Appendix B; Product definitions

This appendix describes how Océ's products are defined. Figure 32 shows the different products, and the attributes belonging to these products. This information is based on a memo written by the business units.

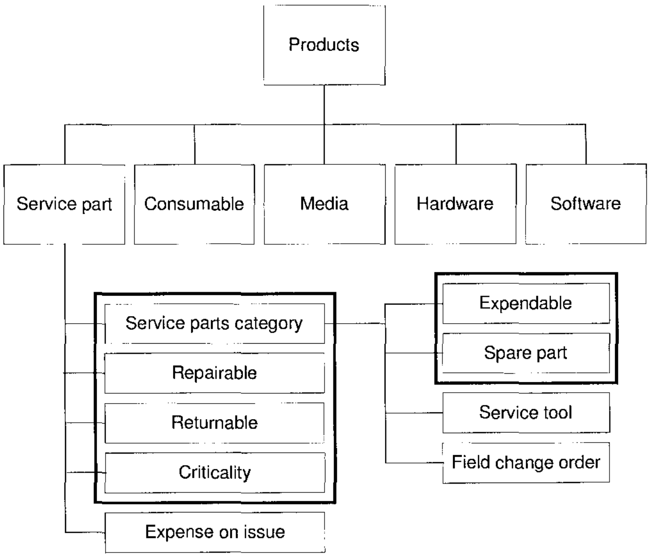


Figure 32; overview of products, and the attributes per product

In total, there are five types of products;

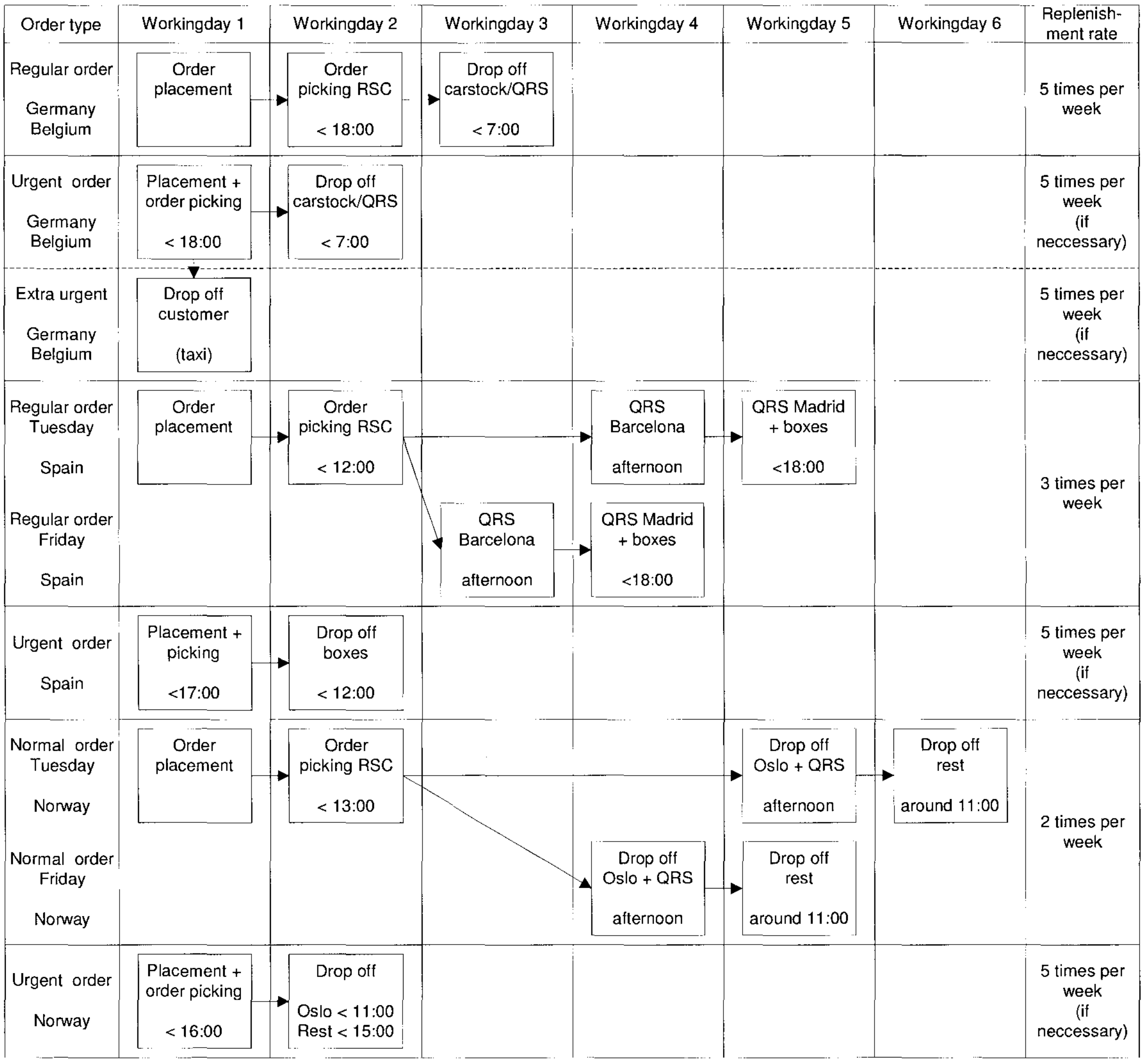
1. Service parts; a service part is an item or a fixed set of items defined for use by service to repair or maintain hardware and software. Technicians can only order service parts via the service parts logistical channel.
2. Consumable; a consumable is a commercial item which is used per transaction, but with a lifespan of multiple transactions. Consumables are part of the print output produced with commercial hardware.
3. Media; A media item is used by a hardware or software product to put the image on the document, or used to combine more than one media item into one document. Media are ordered via the Order To Cash (OTC) sales process.
4. Hardware; One or more commercial items configured in order to execute one or more specific tasks. The items are ordered via the OTC sales process. Examples of hardware are the machines sold by Océ.
5. Software (license); Software is commercially used code, made specifically for a piece of hardware or a customer. Software is ordered via the OTC sales process.

Thereby, each service part has several attributes;

1. Service parts category; this attribute defines to which class the service part belongs to. There are four classes of service parts;
   A. Expendable; this is a service part that is a physical part of hardware products, has a pre-defined lifetime, and has considerable impact on running service costs of the hardware.
   B. Spare part; this is a service part that is a physical part of hardware that can fail, but is not defined as expendable, tool or field change order.
   C. Service tool; A service tool is a service part that is used to maintain or repair hard- or software, but is not a physical part of the hard- or software.
   D. Field change orders; this is a modification for a machine which is pushed by headquarters to the customer or technician.
2. Expense on issue (EOI); an EOI-item is a service part that is not reported on a service job and is not administrated in the carstock. Examples of EOI-parts are stickers, return bags, cleaner, etc.
3. Repairable; a repairable service part is a service part that is feasible for repair by the RSC. Technicians must always return broken repairables to the RSC. If the repairable can be repaired, the OpCo receives a credit.
4. Returnable; a returnable service part should always be returned to the RSC, because of an overstock situation, diagnostic review or for an upgrade. Depending on the condition of the part, the OpCo receives a credit.
5. Criticality; the criticality for printing is defined by the service departments of the business units and is in combination with the service contract the basis for the decision where to stock the part. Service parts can be defined as critical or non-critical.

Appendix C; Order handling and transportation per OpCo

This appendix describes how the selected OpCo's are being replenished, and therefore shows the different ways of replenishments. Figure 33 shows this in a schematic overview.



Order type	Workingday 1	Workingday 2	Workingday 3	Workingday 4	Workingday 5	Workingday 6	Replenishment rate
Regular order Germany Belgium	Order placement	Order picking RSC < 18:00	Drop off carstock/QRS < 7:00				5 times per week
Urgent order Germany Belgium	Placement + order picking < 18:00	Drop off carstock/QRS < 7:00					5 times per week (if neccessary)
Extra urgent Germany Belgium	Drop off customer (taxi)						5 times per week (if neccessary)
Regular order Tuesday Spain	Order placement	Order picking RSC < 12:00		QRS Barcelona afternoon	QRS Madrid + boxes <18:00		3 times per week
Regular order Friday Spain			QRS Barcelona afternoon	QRS Madrid + boxes <18:00			
Urgent order Spain	Placement + picking <17:00	Drop off boxes < 12:00					5 times per week (if neccessary)
Normal order Tuesday Norway	Order placement	Order picking RSC < 13:00			Drop off Oslo + QRS afternoon	Drop off rest around 11:00	2 times per week
Normal order Friday Norway				Drop off Oslo + QRS afternoon	Drop off rest around 11:00		
Urgent order Norway	Placement + order picking < 16:00	Drop off Oslo < 11:00 Rest < 15:00					5 times per week (if neccessary)

Figure 33; overview of order handling and transportation per OpCo

For OpCo's Germany and Belgium, the same order procedure is used. Both OpCo's are replenished five times per week. However, this does not mean that each technician is replenished every working day. If a technician did not use parts or did not order parts, he will not be replenished. Besides the normal urgent orders, both OpCo's have the opportunity to order 'extra urgent orders'. These are the orders that can be delivered by taxi or courier immediately from the RSC to the customer, where the technician needs the service part. For these extra urgent orders, the RSC can be considered as a QRS. In the future, the replenishment rates for Belgium and Germany may be changed from five times per week to two times per week in order to reduce transportation costs.

OpCo Spain is replenished three times per week, with replenishments leaving the RSC on Mondays, Wednesdays and Fridays. These orders are first delivered in Barcelona and Madrid, and then distributed over the rest of the country. The total travelling time to Madrid is longer than the travelling time to Barcelona. The orders picked at the RSC on Friday are delivered in Barcelona on Monday morning, and in Madrid on Monday afternoon or Tuesday morning. A problem for the Friday-orders is the transport legislation in France. Trucks are not allowed to drive in France between Saturday 22:00 and Sunday 22:00. This means that trucks do not always arrive on time in Spain on Mondays, making the delivery unreliable. For the urgent orders the following guideline is applicable; an urgent order ordered before 17:00 is delivered before 12:00 the next day, but in reality often before 10:00. The delivery time depends on the location where the parts have to be delivered. Most technicians pick up their replenishment at drop off points.

The regular orders for Norway are also picked on Tuesdays and Fridays in the RSC. The Friday-orders arrive in Oslo on Tuesday afternoon, and Wednesday morning in Stavanger, Bergen and Trondheim. The orders picked on Tuesday arrive in Oslo Friday afternoon, and the other cities are supplied on Monday. Most technicians pick up their ordered service parts at drop off points. Urgent orders can be ordered every day before 16:00. These orders arrive in Oslo between 10:00 and 11:00 the next day. In Stavanger, these orders arrive around 15:00 and in Bergen and Trondheim between 13:00 and 14:00.

Appendix D; Carstock model

This appendix contains a more mathematical description of the carstock model. The use of the carstockmodel by the OpCo's is described in Section 4.4.1.

In general, the model calculates for every service part whether it is economically justified to store the service part in the carstock. If the costs of the second visits costs are larger than the cost of keeping the part on stock, the service part can be stored in the carstock. Then, for each service part the optimal carstock quantity is determined by calculating different inventory positions until the most economical inventory position is found. It is assumed that the demand of service parts is distributed according to a Poisson distribution.

Therefore, the model takes the following parameters into account:

- Total expected usage (EU): Expected usage per technician in the coming year. This is calculated by using national installed base data, combined with historical data about visits for certain service parts and machines. These data are adjusted for a certain region, in which multiple technicians form a group. For the population in that region, each technician is responsible for a certain percentage of the machines of that population.
- Used quantity (UQ): The used quantity shows how many items are needed if a certain part is needed for a repair.
- Cost price: ICP (Inter Company Price). This is the price charged to the OpCo for buying the service part.
- Rent Risk Room Factor (RRR): Factor used to calculate the costs of keeping inventory of the service part. To calculate the costs of keeping inventory, the ICP is multiplied by the RRR-factor.
- Second visit cost (C_{sv}): Costs of a second visit due to a lack of service parts.
- Replenishment time of the technician in days; (T).
- Carstock inventory level *y* for a certain service part.
- Demand during replenishment time; D.

A product is defined as a carstock item if the following formula is true:

$$EU > \frac{(RRR \cdot UQ \cdot ICP)}{C_{sv}} \quad \rightarrow \quad \frac{(EU \cdot C_{sv})}{UQ} > (RRR \cdot ICP) \qquad (1)$$

→ Total costs 2nd visits > total inventory costs

This formula calculates for every service part whether it is economical to keep the service part in the carstock. If the costs of the second visits costs are larger than the costs of keeping the part on stock, the service part can be stored in the carstock.

Then, for all the service parts for which formula 1 is true, the total costs (TC) are calculated for different values of stocklevel *y*. The total costs are defined as the costs for the second visits plus the costs of keeping inventory level y;

$$TC(y) = P(D(t) = y + 1) \cdot C_{sv} + RRR \cdot ICP \cdot y \text{, for } y = 0,1,2... \qquad (2)$$

Thus, for each service part the optimal carstock inventory is determined by recalculating the inventory position until the most economical position is found. The costs for the second visits are calculated by calculating the probability of a backorder during replenishment time *t*. It is assumed that the demand of service parts is distributed according to a Poisson distribution.

After these two calculations, there are too many items selected to fit in the carstock. Especially the low value, low demanded parts are advised in quite large quantities, because the costs for a second visit for these parts will always be higher than the inventory costs for these parts. In order to reduce the number of items, a usage restriction is introduced. This restriction removes service parts from the list if their expected usage is below a certain usage level. Two usage levels are used (X1 and X2), resulting in two categories of service parts; advised parts and strongly advised parts. Thereby the following guidelines apply:

1. Strongly advised; Total expected usage service part > X1
2. Advised; Total expected usage service part > X2,

Whereby X1 > X2

Besides these two categories, three other categories are defined;

3. Not advised, but economically justified parts. These parts meet the requirements of formula 1, but their expected usage is smaller than X2. The advised normstock for these parts is equal to 0.
4. Pre-advised parts. These are the parts marked by the service department as service parts that need to be in a carstock, but not necessarily belong to categories 1 or 2.
5. Not advised parts currently identified as carstock parts. These are category 3 parts, but the decision was taken to store these parts in the carstock.

Appendix E; Demand distribution

To be able to model the service parts supply chain, a probability distribution is required to describe the demand for service parts. In service parts literature it is often assumed that the demand for service parts behaves as a Poisson process. This assumption is widely used in literature to describe the demand for service parts, because the lifetime of a part within a machine is often distributed according to the exponential distribution. This results in a demand process that can be described by the Poisson distribution.

The most common method to test whether data can be described by a certain probability distribution, is the Chi-square test (Montgomery, 1999). In this case, the Chi-square test is used to test the following hypothesis: the demand per four weeks can be described by a Poisson distribution for each service part for each location.

However, the Chi-square test requires a minimum demand per four weeks, in order to obtain reliable results. If the demand per carstock would be analysed, the demand is too low to execute a good analysis. Therefore, the demand for service parts for more locations needs to be analysed. To do this, OpCo Norway is selected, because this OpCo is relatively small and it has one QRS, making it a single QRS-region. This makes it the closest approximation of the demand per fieldstock location. A significance level of 5% was used. This means that the probability that the hypothesis is incorrectly rejected does not exceed 5%.

To execute this analysis, a list is generated with all service parts with the demand per four weeks over the past two years. The period of four weeks is chosen in order to increase the demand per period, so more reliable tests can be executed. If the demand per four weeks is Poisson distributed, the demand per six months or one year is also Poisson distributed. The optimisation program will be used to calculate basestock levels based on forecasted demand for six months or one year.

The four weeks period result in 26 periods over the two years that contain demand data. Then, these periods are categorised based on the demand per period. For example, all months with a demand between 13 and 18 items belong to one category. The number of periods that a category of demand occurred can be regarded as the number of observations. For example, if 5 periods faced a demand between 13 and 18 parts, this can be regarded as 5 observations. Whenever a category contains less than three observations, categories are combined in order to execute a reliable analysis. Another reliability requirement is that the number of categories must be larger than four.

The analysis was executed by using Statgraphics. An example of the output can be found in Figure 34.

```
Goodness-of-Fit Tests for Col_1

                              Chi-Square Test
----------------------------------------------------------------------------
               Lower         Upper     Observed      Expected
               Limit         Limit    Frequency     Frequency    Chi-Square
----------------------------------------------------------------------------
          at or below          6,5            3          2,26          0,24
                  6,5          8,5            5          4,23          0,14
                  8,5          9,5            2          2,92          0,29
                  9,5         10,5            2          3,15          0,42
                 10,5         11,5            4          3,10          0,26
                 11,5         12,5            2          2,79          0,22
                 12,5         13,5            2          2,32          0,04
                 13,5         15,5            3          3,08          0,00
above            15,5                         3          2,15          0,34
----------------------------------------------------------------------------
Chi-Square = 1,96331 with 7 d.f.   P-Value = 0,961843
```

Figure 34; Example of the output screen of Statgraphics

The output table shows that for each class an observed frequency is compared with the expected frequency. The difference between these frequencies provides a Chi-square value per demand class. The sum of these Chi-squares is the total Chi-square for the analysis, which is equal to 1,96331 in this analysis. This can be compared with the Chi-squared distribution for parameters $\alpha = 0{,}05$ and seven degrees of freedom. This value is equal to 14,07 (Montgomery, 1999). This means that a Poisson distribution cannot be rejected as long as the analysis output is below 14,07. In this case, the Poisson distribution cannot be rejected, because the Chi-square output of 1,96 is smaller than 14,07.

96 Parts had sufficient demand to execute a proper Chi-square test. For 82 of those 96 parts (85%) the hypothesis of a Poisson distribution could not be rejected. For three service parts, a normal distribution could not be rejected. These service parts had a relatively high demand. For the other eleven service parts, no suitable demand distribution could be found. These demand patterns may be different due to events like technical changes, changing work procedures or seasonal effects. When using the optimisation model, these events can be excluded from the optimisation.

As a conclusion it can be said that the demand for service parts at the fieldstock locations can be described by a Poisson distribution. There is no reason to assume that the demand pattern at other OpCo's is different than the demand patterns at OpCo Norway. The same is true for the service parts that were not used for this analysis. These service parts have the same characteristics as the tested service parts, except for the lower demand.

Appendix F; Calculation algorithm

This appendix describes the calculation algorithm in more detail. This algorithm is used by the optimisation algorithm to determine the performance of a specific fieldstock configuration. The explanation in this appendix is more extensive, and generic than the explanation in Chapter 7. It is applicable for every fieldstock setting at Océ.

Introduction

An exact evaluation of an inventory policy for a multi-location situation takes a lot of time, and is sometimes even impossible. This is due to the fact that by adding an extra local warehouse, an extra dimension in the Markov process needs to be added. A Markov process is a method that can be used to calculate steady-state probabilities for systems. Therefore, Kranenburg (2006) developed an approximate evaluation method, which reduces the state spaces in the Markov process. This results in a fast and accurate method to calculate the steady state probabilities. This method is described in more detail in this appendix.

The state space is reduced because Kranenburg decouples the regular warehouses from the main warehouse, and the main warehouses from each other. Decoupling these warehouses makes it possible to analyse each warehouse individually. The analysis is executed for each service part separately. In Chapter 7, a distinction is made between the basic situation with one local warehouse (QRS) per region, and the extended situation with more main local warehouses. This appendix describes the extended situation, and is therefore also applicable for the basic situation.

Decoupling the regulars from the mains

For the first decoupling step, Kranenburg decouples the regular local warehouses from the main local warehouses. These warehouses are connected to each other, because demand at a main local warehouse occurs when regular warehouse *j* does not have demanded part *i* in stock. The demand from a regular local warehouse to a main local warehouse is called the overflow demand process at regular *j*. It is assumed that this overflow demand from regular *j* behaves as a Poisson process that constitutes an additional demand stream at main k_j. In reality, the overflow demand may be 'burstier' than a Poisson demand, but with low demand rates this assumption is reasonable.

By assuming a Poisson process for the overflow demand, it is possible to decouple the main warehouses from the regular warehouses, because a Poisson demand arrives at the main warehouses. The fill rate of each regular warehouse can be analysed separately. If the fill rate for regular *j* is known, the overflow demand from regular *j* can also be calculated. By using this overflow demand, each main warehouse can be analysed, because this is the demand that occurs at this main warehouse.

The fill rate per local warehouse can be calculated by using the Erlang Loss model, with demand rate $M_{i,j}$, basestock level $S_{i,j}$ and replenishment time t^{reg} as input. Because the Erlang Loss model calculates the fraction of the demand that cannot be fulfilled, the fill rate per local warehouse can be calculated by using $\beta_{i,j}(S_i) = 1 - L(S_{i,j}, M_{i,j} t^{reg})$. This formula for the fill rates of the regular warehouses is exact. The overflow demand of regular warehouse *j* for part *i* is equal to $1 - \beta_{i,j}(S_i)$. In total, this results in a demand from regular *j* to main k_j that is equal to $(1 - \beta_{i,j}(S_i))M_{i,j}$ items per year.

In total, main warehouse *k* has to fulfil autonomous demand $M_{i,k}$, and the demand of all regular warehouses assigned to main warehouse *k*. Then, the total demand rate at main *k* is equal to $\tilde{M}_{i,k} := M_{i,k} + \sum_{j \in J | k_j = k} (1 - \beta_{i,j}(S_i))M_{i,j}$. If main *k* is a QRS, no autonomous demand occurs at *k*, and in that case $M_{i,k} := 0$. Main *k* may not be able to fulfil all the demand, and therefore this main warehouse may also cause an overflow demand. If there is only one main warehouse, this overflow demand will be fulfilled by the central warehouse. If there are more main warehouses that are connected to each other, the overflow demand needs to be fulfilled by other main warehouses. To calculate this overflow demand, the main warehouses are decoupled from each other. This is described in the next Section.

Decoupling the mains

By decoupling the main warehouses from each other, each main warehouse can be analysed separately. Similar to the first decoupling step, it is assumed that the overflow demand from main *k* behaves as a Poisson process. Again, this overflow demand can be 'burstier' than a Poisson process. However, by assuming a Poisson process it is possible to decouple the mains from each other, and analyse them separately.

First, by considering the aggregate system of all main local warehouses, the overflow demand from these mains to the central warehouse ($\theta_{i,k}(S_i)$, $k \in K$) can be determined. Note that $\theta_{i,k}(S_i)$, $k \in K$ is equal for all mains, because it is assumed that all mains are connected to each other. The overflow demand is calculated by using the Erlang Loss Model, with demand rates $\tilde{M}_{i,k}$, basestock levels $S_{i,k}$ and replenishment time t^{reg} as input. Then, $\theta_{i,k}(S_i)$, $k \in K$ is calculated by; $\theta_{i,k}(S_i) := L(\sum_{k\in K} S_{i,k}, \sum_{k\in K} \tilde{M}_{i,k} t^{reg})$, $k \in K$. This is an exact calculation.

Vector $\sigma(k) := (\sigma_1(k),..,\sigma_{|K|-1}(k))$ shows the pre-specified order of mains for main warehouse *k* which are checked for the availability of the demanded parts. Thereby, each main local warehouse other than *k* appears exactly once in this vector. $K(k,\tilde{k}) \subset K$ is defined as the subset of main local warehouses with a lower position number than main local warehouse $\tilde{k}$, in the pre-specified order for main *k*. This means that all predecessors of $\tilde{k}$ are part of subset $K(k,\tilde{k}) \subset K$. Then, $\hat{M}_{i,\tilde{k},k}, k,\tilde{k} \in K, \tilde{k} \neq k$ is introduced as the rate for which main $\tilde{k}$ requests a lateral transhipment from main *k*. In total, all other mains demand a quantity of $\sum_{\tilde{k}\in K,\tilde{k}\neq k} \hat{M}_{i,\tilde{k},k}, k \in K$ service parts at main *k*. Then, the total demand at main *k*, which is expressed as $\hat{M}_{i,k}$, is equal to $\hat{M}_{i,k} := \tilde{M}_{i,k} + \sum_{\tilde{k}\in K,\tilde{k}\neq k} \hat{M}_{i,\tilde{k},k}, k \in K$. If this demand is known, each main local warehouse can be analysed by using the Erlang loss model. For each main $k \in K$, the fill rate can be calculated by $\beta_{i,k}(S_i) := 1 - L(S_{i,k}, \hat{M}_{i,k} t^{reg})$. The fraction of service parts delivered by a lateral transhipment from other main warehouses to main *k* is equal to $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$.

However, it is not yet possible to calculate the fraction of lateral transhipments per main local warehouse. Thus, $\hat{M}_{i,\tilde{k},k}, k,\tilde{k} \in K, \tilde{k} \neq k$ is not known yet. For each main *k*, this factor can be calculated by using an iterative procedure. Therefore, initially it is assumed that no lateral transhipment takes place between the mains, thus $\hat{M}_{i,k} := \tilde{M}_{i,k}$, $k \in K$. By using the equation $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$, the fraction of the demand at main *k* delivered by other main warehouses can be determined. Because $A_{i,k}(S_i)$ represents the demand from main *k* to the other mains, it can be used to calculate the demand at the other mains, caused by main *k'*. Thereby, $\hat{M}_{i,\tilde{k},k} = \dfrac{A_{i,\tilde{k}}(S_i)\tilde{M}_{i,\tilde{k}}}{1-\prod_{l\in K, l\neq \tilde{k}}(1-\beta_{i,l}(S_i))} \prod_{l\in K(\tilde{k},k)}(1-\beta_{i,l}(S_i))$, with the condition that $S_{i,l} > 0$ for at least one $l \in K \setminus \{\tilde{k}\}$, otherwise $\hat{M}_{i,\tilde{k},k} = 0$. Furthermore, $\prod_{l\in K, l\neq \tilde{k}}(1-\beta_{i,l}(S_i)) := 1$ if $K(k,\tilde{k})$ = $\varnothing$. Using this formula gives $\hat{M}_{i,\tilde{k},k}, k,\tilde{k} \in K, \tilde{k} \neq k'$. Then, $\hat{M}_{i,k'}$, $\beta_{i,k'}(S_i)$ and $A_{i,k'}(S_i)$ can be determined. This can be repeated for all other mains $k \in K$, followed by main *k'* again. This can be repeated until $\hat{M}_{i,k'}$, $k \in K$ each do not change more than ε, with ε small. By applying the iterative procedure, the lateral transhipment rates can be calculated and refined until the outcomes do not change anymore.

To clarify this procedure, an example is given. This is the same example as Kranenburg uses in his paper. Assume that there are three mains (1,2 and 3), and $\sigma(1) = (2,3)$. Thus, when main 1 cannot fulfil demand, first main 2 is checked, followed by main 3. For the iterative procedure, it is initially assumed that no lateral supply takes place between the mains. For each main, the fill rate can be estimated by $\beta_{i,k}(S_i) = 1 - L(S_{i,k}, M_{i,k} t^{reg})$.

Then, the total fraction of demand delivered by lateral supply can be determined by using the fill rate for each main, and the total fraction of urgent supply; $A_{i,k}(S_i) := 1-(\beta_{i,k}(S_i)+\theta_{i,k}(S_i))$. Then, for one main, say main 1, an estimation can be made for the lateral transhipment rate from main 2 and main 3 to main 1. For main 2, a fraction $\beta_{i,2}(S_i)$ of the demand rate $\hat{M}_{i,1,2}$ from main 1 can be fulfilled. Because main 2 fulfils a fraction of the overflow demand from main 1, the total demand rate at main 3 is smaller, and equal to $\hat{M}_{i,1,3} := (1-\beta_{i,2}(S_i))\hat{M}_{i,1,2}$. In total, a fraction of the overflow demand that is equal to $(1-(1-\beta_{i,2}(S_i))(1-\beta_{i,3}(S_i)))$ can be delivered to main 1. In total, a fraction $A_{i,1}(S_i)$ of demand rate $\tilde{M}_{i,1}$ at main 1 is supplied by mains 2 and 3. Therefore, the demand rate from main 1 to main 2 is equal to $\hat{M}_{i,1,2} = \dfrac{A_{i,1}(S_i)\tilde{M}_{i,1}}{1-(1-\beta_{i,2}(S_i))(1-\beta_{i,3}(S_i))}$. Because main 2 supplies most of the lateral transhipment to main 1, the lateral supply from main 3 to main 1 is smaller, with factor $(1-\beta_{i,2}(S_i))$. This results in the following formula;

$$\hat{M}_{i,1,3} = \frac{A_{i,1}(S_i)\tilde{M}_{i,1}}{1-(1-\beta_{i,2}(S_i))(1-\beta_{i,3}(S_i))}(1-\beta_{i,2}(S_i)).$$

When these lateral transhipment rates are known, the total lateral demand rate from main 1 ($\hat{M}_{i,1}$), the fill rate of main 1 ($\beta_{i,1}(S_i)$), and the lateral transhipment rate ($A_{i,1}(S_i)$) can be calculated. This procedure is repeated for the other two mains as well, and starts over with main 1, until $\hat{M}_{i,k}$ does not change more than ε for each main *k*. Thereby, ε is small. Kranenburg observed that this procedure converges in all case, but there is no formal proof for the convergence.

When the results for the decoupled mains are found, all performance measures for the regular local warehouses can be found as well. This results in;

$\alpha_{i,j,k}(S_i) := (1-\beta_{i,j}(S_i))\beta_{i,k_j}(S_i)$ for $k = k_j$, and

$\alpha_{i,j,k}(S_i) := (1-\beta_{i,j}(S_i))\alpha_{i,k_j,k}(S_i)$ for $k \in K, k \neq k_j$

$\theta_{i,j}(S_i) := (1-\beta_{i,j}(S_i))\theta_{i,k_j}(S_i)$

$A_{i,j}(S_i) := 1-(\beta_{i,j}(S_i)+\theta_{i,j}(S_i))$

Other service measures, such as the total costs can be calculated by using these performance measures. This is described into more detail in Section 7.2.2. The procedure described above can be written down in the following two algorithms;

Algorithm 1

The derivation described in the previous section, results in the following algorithm;

Step 1; For all regulars $j \in J \setminus K$; $\beta_{i,j}(S_i) = 1 - L(S_{i,j}, M_{i,j}t^{reg})$

Step 2; For all mains $k \in K$; $\tilde{M}_{i,k} := M_{i,k} + \sum_{j \in J|k=k}(1-\beta_{i,j}(S_i))M_{i,j}$

Step 3; For all mains $k \in K$, determine $\beta_{i,k}(S_i)$, $\alpha_{i,k,\tilde{k}}(S_i)$, $\tilde{k} \in K$, $\tilde{k} \neq k$, and $\theta_{i,k}(S_i)$ using algorithm 2.

Step 4; For all regulars $j \in J \setminus K$, if $K = \varnothing$, then $\theta_{i,j}(S_i) := (1-\beta_{i,j}(S_i))$.
Otherwise, for $k = k_j$ use $\alpha_{i,j,k}(S_i) := (1-\beta_{i,j}(S_i))\beta_{i,k_j}(S_i)$, and for $k \in K, k \neq k_j$ use $\alpha_{i,j,k}(S_i) := (1-\beta_{i,j}(S_i))\alpha_{i,k_j,k}(S_i)$, and $\theta_{i,j}(S_i) := (1-\beta_{i,j}(S_i))\theta_{i,k_j}(S_i)$.

Algorithm 2

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

Step 2; For all mains $k \in K$, $\beta_{i,k}(S_i) := 1 - L(S_{i,k}, \tilde{M}_{i,k} t^{reg})$, and $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$

Step 3; For one main $k \in K$:

Step 3a; $\hat{M}_{i,\tilde{k},k} = \dfrac{A_{i,\tilde{k}}(S_i)\tilde{M}_{i,\tilde{k}}}{1 - \prod_{l\in K, l\neq\tilde{k}}(1-\beta_{i,l}(S_i))} \prod_{l\in K(\tilde{k},k)}(1-\beta_{i,l}(S_i))$

With the condition that $S_{i,l} > 0$ for at least one $l \in K\setminus\{\tilde{k}\}$; otherwise $\hat{M}_{i,\tilde{k},k} = 0$.

Furthermore, $\prod_{l\in K, l\neq\tilde{k}}(1-\beta_{i,l}(S_i)) := 1$ if $K(k,\tilde{k}) = \emptyset$.

Then, calculate $\hat{M}_{i,k} := \tilde{M}_{i,k} + \sum_{\tilde{k}\in K, \tilde{k}\neq k} \hat{M}_{i,\tilde{k},k}$

Step 3b; $\beta_{i,k}(S_i) := 1 - L(S_{i,k}, \hat{M}_{i,k} t^{reg})$, and $A_{i,k}(S_i) := 1 - (\beta_{i,k}(S_i) + \theta_{i,k}(S_i))$

Step 4; Repeat step 3 for all other mains $k \in K$

Step 5; Repeat steps 3 and 4 until $\hat{M}_{i,k}$ does not change more than ε for each $k \in K$, with ε small.

Step 6; For all mains $k \in K$, $\alpha_{i,k,\tilde{k}}(S_i) := \beta_{i,\tilde{k}}(S_i)\dfrac{\hat{M}_{i,k,\tilde{k}}}{\tilde{M}_{i,k}}$, $\tilde{k} \in K$, $\tilde{k} \neq k$