MASTER

Service part inventory management taking into account storage capacity restrictions and dynamic and static inventory locations

van Dijk, R.F.G.

Award date:
2014

Link to publication

Disclaimer
This document contains a student thesis (bachelor's or master's), as authored by a student at Eindhoven University of Technology. Student theses are made available in the TU/e repository upon obtaining the required degree. The grade received is not published on the document as presented in the repository. The required complexity or quality of research of student theses may vary by program, and the required minimum study period may vary in duration.

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
Service part inventory management taking into account storage capacity restrictions and dynamic and static inventory locations

by

Ruud van Dijk

BSc Industrial Engineering, 2011
Student identity number 0618624

in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Company supervisors:
William Mimpen
Bas Plaum

TU/e supervisors:
1st assessor: dr. ir. H.P.G. van Ooijen
2nd assessor: ir.dr. S.D.P. Flapper
Subject headings: inventory control, spare parts, storage capacity restrictions, seasonal demand, forecasting
Abstract

This master thesis describes the development of a model to determine base stock inventory levels for a service part distribution network with the goal of minimizing supply chain costs for a given target fill rate performance level. The network consists of geographically static and dynamic inventory locations subject to storage capacity restrictions. The model is tested on data from a real-life service part distribution network and the consequences of long term application are investigated.
Preface

This master thesis report is the end result of the research project conducted at Ricoh Netherlands and also the final stage of the master Operations, Management and Logistics at the University of Eindhoven. The project focused on service part inventory management for the distribution network of an after sales service system.

I would like to thank Ricoh Netherlands for providing me with the opportunity to perform this project at their company. Furthermore, I would like to thank my two company supervisors, William Mimpen and Bas Plaum, for their support and interest in my project. Throughout the duration of my project they have provided me with both advice and information and helped me to get in contact with other employees within the company. Three other employees I would like to mention and thank for their help are Stefan Baars, Maarten van Houdt and Rob Blok who have helped me numerous times during my project. Last but not least, I would like to thank the employees from the department of Supply Chain Management for the nice conversations and the great atmosphere.

I would also like to thank my two university supervisors, Henny van Ooijen and Simme Douwe Flapper for their critical feedback and their useful advice to help me move forward whenever I reached a deadlock or went off track.

Finally I would like to thank my girlfriend and my friends and family for their interest in my project but most of all for helping me get my mind off of the project occasionally, so I would be able to start fresh again the next day.
Management Summary

This research focuses on service part inventory management for the distribution network of an after sales service organization. The methodology designed in this research has been tested on the service part distribution network at Ricoh Netherlands.

The after sales service system at Ricoh Netherlands is characterized by service engineers that are sent to customers to perform corrective maintenance on installed machines which sometimes involves replacing certain components. Contracted service level agreements (SLAs) regarding maximum response and repair times are made with the customer and the goal of the after sales service system is meeting the SLAs it has with its customers. The service parts that are sometimes required are made available to the service engineers at fieldstock locations. These consist of the cars of the engineers with which they visit the customers and the static stock locations from where service engineers can retrieve service parts. All fieldstocks are subject to storage capacity constraints. Currently, inventory levels at the fieldstock locations are determined without the use of any centrally determined guidelines. Service engineers are responsible for determining the inventory at the fieldstock locations and to make sure they do not fall short on service parts. In practice this results in service engineers stocking service parts they might not really need. A technical malfunction which occurs at low temperatures causes the failure rates of certain service parts to increase. The demand fluctuations this phenomenon creates further contribute to this problem.

Inventory management is currently not based on informed decision making and the effects of inventory levels on customer service and supply chain costs are unclear. Therefore Ricoh Netherlands is interested in finding out what the consequences of lowering the amount of service parts in inventory are for the supply chain costs, while accounting for the consequences of doing so on their performance levels. This results in the following research assignment:

"Develop a tool to determine the optimal inventory levels and supply chain costs given a desired service level taking into account storage capacity restrictions for a service part distribution system with dynamic and static inventory locations."

The tool is designed to determine base stock inventory levels for a system which distinguishes three ways through which demand is fulfilled; (1) fulfilment by a carstock, (2) fulfilment by a lockerpoint, or (3) fulfilment at a later moment – i.e. a return visit is planned and the service part is urgently delivered. These fulfilment options each have different costs related to them. A target service level is set for the first visit fill rate, which is defined as the percentage of demand which is fulfilled from a carstock or the lockerpoint. The target first visit fill rate should be met for each carstock. Service engineers are assumed to only visit the lockerpoint closest to their
home and the distribution system considered in the research therefore considers only 1 lockerpoint. Because service part demand can be subject to fluctuations caused by seasonal effects, the base stock levels should be updated over the course of time. Therefore this research also analysed the effect of applying different base stock level update frequencies and two different demand forecasting methods on the cost and fill rate performance of the tool.

Results

- The fieldstock model was found to reach a 99.6% fill rate performance due to the high cost of a second visit.
- Compared to the real-life performance during 2013, the fieldstock model was able to achieve an improvement of the first visit fill rate performance from 77.9% to 92.4%, and a reduction of supply chain costs by 13%, by doubling the inventory investment. Average machine downtime was found to decrease by 30%.
- Because the fieldstock model tries to maximize the inventory levels with the goal of preventing expensive second visits, storage capacity was found to be insufficient for 13 of the 16 engineers. When the storage capacity was increased by offering the largest available service vehicle, only one service engineer had insufficient storage capacity, resulting in a decrease in supply chain costs (including the costs of these larger vehicles) of 13% compared to the current storage capacity restrictions.
- The fieldstock model was tested by considering the consequences of using the model to update the inventory base stock levels at different frequencies over a period of 3 years. Updating the base stock levels once a year was found to be best both with regard to the supply chain costs and the fill rate performance. Considering seasonality for the review period of 6 months using the Holt-Winters forecasting method was found not to contribute to improved inventory management given the dataset used in this research. Both the costs and the fill rate performance were found to be similar to those achieved by using a simple moving average.

Main conclusions and recommendations

Based on the results of the case study three main conclusions have been drawn:

- The fieldstock model developed in this research can assist with service part inventory management and give insight into the relationship between the inventory levels and the cost and fill rate performance. The model can support decision making and allows Ricoh to analyse the consequences of different scenarios such as changing cost parameters and changes in their service strategy.
- The relatively high costs related to performing a second visit show that sufficient
  inventory is of importance to prevent second visits as much as possible.

- The fieldstock model was found to achieve a performance of 92.4% compared to the
  actual performance of 77.9% achieved during 2013.

- Increasing the storage capacity by using larger service vehicles was found to allow for a
  decrease in supply chain costs, showing that increasing the storage capacity of the
  fieldstock locations is justified and worth considering by Ricoh from a cost perspective.

Several recommendations are made to guide Ricoh in possible follow up research:

- To enable adequate use of the fieldstock model, inventory management should not only
  be based on the tool designed in this research. This will most likely cause engineers to
  lose interest in being actively concerned with inventory management because they are
  no longer held responsible for it. By giving the tool a supporting role in monitoring the
  performance of service engineers more closely, this can ensure keeping them actively
  engaged in improving inventory management.

- Further research into the consequences of inventory management on the entire supply
  chain is needed as findings suggest increasing the fieldstock inventory levels for Ricoh
  Netherlands can reduce costs while Ricoh Europe is focused on lowering inventory.

- Responsibility for the lockerpoints should be centralized and lie with the group or
  person responsible for managing and applying the tool, as this tool has shown to provide
  good insight into what should be stored at a lockerpoint.

- Although the fieldstock model suggests a solution for which about 25% of demand is
  fulfilled from the lockerpoint, service part usage from the lockerpoints should be
  monitored to determine whether service engineers really make use of them. This will
  help determine which service engineers visit which lockerpoints, allowing for inventory
  at that lockerpoints to be managed according to the actual demand experienced there.

- The problem of incorrect part registration should be solved because it seriously limits
  any success achieved from performing inventory control based on this information.

- By limiting the number of different skills that service engineers are trained on, the
  variety of service parts for which a service engineer experiences demand can be limited,
  resulting in a possible reduction of the diversity in service part demand and allowing for
  a lower diversity of service parts in inventory and lower total inventory. As this might
  come at the cost of lowering planning flexibility, further research should be done to
  determine whether the benefits regarding inventory management outweigh this downside.
# Table of Contents

Abstract ................................................................................................................................................................................. ii  
Preface................................................................................................................................................................................... iii  
Management Summary .................................................................................................................................................. iv  
Table of Contents ............................................................................................................................................................. vii  
Definitions ........................................................................................................................................................................... ix  
Abbreviations .......................................................................................................................................................................x  

1. Introduction ............................................................................................................................................................... 1  
   1.1. Ricoh Netherlands ............................................................................................................................................. 1  
   1.2. Research trigger ............................................................................................................................................. 2  
   1.3. Problem overview ......................................................................................................................................... 3  
   1.4. Report Outline ................................................................................................................................................ 5  
   1.5. Conclusion ........................................................................................................................................................ 5  

2. Research Design ....................................................................................................................................................... 6  
   2.1. Literature review ........................................................................................................................................... 6  
   2.2. Research Assignment .................................................................................................................................. 8  
   2.3. Conclusion ..................................................................................................................................................... 11  

3. Detailed analysis Ricoh ....................................................................................................................................... 12  
   3.1. Service part distribution network ........................................................................................................... 12  
   3.2. After sales service system ....................................................................................................................... 13  
   3.3. Service part inventory analysis ............................................................................................................ 16  
   3.4. Conclusion ..................................................................................................................................................... 19  

4. Model description ................................................................................................................................................. 21  
   4.1. Model choice ................................................................................................................................................ 21  
   4.2. Adjustment of the model by Kranenburg ......................................................................................... 21  
   4.3. Performance measures ............................................................................................................................ 22  
   4.4. Mathematical model .................................................................................................................................. 25  
   4.5. Procedure to solve the model ............................................................................................................... 29
4.6. Programming language ............................................................................................................................ 31
4.7. Conclusion ..................................................................................................................................................... 31

5. Base stock level updating ............................................................................................................................ 32
  5.1. Process of updating ................................................................................................................................... 32
  5.2. Cost of updating .......................................................................................................................................... 32
  5.3. Comparing update frequencies ............................................................................................................ 33
  5.4. Conclusion ..................................................................................................................................................... 34

6. Ricoh case study ............................................................................................................................................... 35
  6.1. Assumptions ................................................................................................................................................. 35
  6.2. Input Parameters ....................................................................................................................................... 37
  6.3. Results ............................................................................................................................................................. 44
  6.4. Conclusions ................................................................................................................................................... 50

7. Implementation plan ...................................................................................................................................... 52
  7.1. Responsibility tool ..................................................................................................................................... 52
  7.2. Basis of support within Ricoh ............................................................................................................... 52
  7.3. Limitations .................................................................................................................................................... 53

8. Conclusions and recommendations .............................................................................................................. 55
  8.1. Main conclusions ........................................................................................................................................ 55
  8.2. Recommendations ..................................................................................................................................... 56
  8.3. Theoretical contribution ......................................................................................................................... 57

Bibliography .......................................................................................................................................................... 58

Appendix A. Regions and Service Engineers ................................................................................................... 60
Appendix B. Algorithms to solve the model ..................................................................................................... 62
Appendix C. Poisson distributed demand ........................................................................................................ 66
Appendix D. Forecast method .......................................................................................................................... 67
### Definitions

**Carstock**
- The service parts that service engineers store in the service vehicles with which they visit a customer

**Corrective maintenance**
- Maintenance executed in response to a service request

**Customerstock**
- The service parts stored at a customer, which are only used for that customer

**European Spare Parts Centre (ESPC)**
- The central warehouse for Ricoh Europe which replenishes the European OpCo’s and also acts as a regional warehouse for the Dutch OpCo

**Fieldstock locations**
- The locations in the field at which service parts are stored; three different types of stock are considered; carstock, lockerstock and customerstock

**First visit**
- The first attempt to fix a machine breakdown at a customer

**First visit fill rate**
- This measure represents the percentage of successful repairs a service engineer has performed during the first visits that required one or more service parts

**Hardware & Inbox Solutions**
- The department responsible for supporting and monitoring the service engineers

**Lockerstock**
- The service parts stored at a lockerpoint which is used as an extra stock location from where service engineers can retrieve service parts

**Month on Hand (MoH)**
- The ratio between the total value of monthly demand and the total inventory value

**Obsolescence costs**
- Costs of a spare part becoming redundant because there are no longer any machines in operation or because the part has been replaced by a successor

**Office Printing (OP)**
- The group of printers that print at a rate of 60 prints per minute or less

**Operating Company (OpCo)**
- An independent operating unit that is part of a larger company

**Operations Planning & Monitoring**
- The department responsible for coordinating the logistics associated with delivery and installation of machines and service parts

**Opportunity costs**
- The cost of keeping parts in inventory caused by not being able to invest the money spent on inventory in any other profitable endeavours

**Overflow demand**
- The service part demand a fieldstock experiences due to service parts requested by another fieldstock

**Preventive maintenance**
- Maintenance executed on a component in the machine, when its cycle count has reached a certain threshold

**Production Printing**
- The group of printers that can print at a rate of over 60 prints per minute
Repair time: The time it takes to get a failed machine to be functional again, from the moment the customer reports a service request.

Response time: The time it takes from the moment the inbound call agent receives the service request, until the moment an engineer is present at the customer.

Return to fit parts: This is a return visit needed when an engineer was not able to fix a problem because he did not have the necessary service part(s).

Second visit: The second attempt to fix a machine breakdown at a customer.

Service engineer: The engineers that visit customers to provide maintenance.

Service Level Agreement (SLA): A contractual agreement on the level of service to be provided by a service provider to a customer.

Service request: The reporting of a machine breakdown by a customer.

Service time: The amount of time a service engineer spends while visiting the customer.

Service visit: The visit to a customer who reported a problem, by a service engineer.

Storage costs: Costs such as rent and insurance.

Supply Chain Management: The department responsible for purchasing, machine delivery and all assets.

**Abbreviations**

BS: Base Stock
ESPC: European Spare Parts Centre
HW: Holt-Winters forecasting method
KPI: Key Performance Indicator
MoH: Month on Hand
MTD: Monthly Total Demand
MTS: Monthly Total Stock
NIP: Nonlinear Integer Problem
OP: Office Printing
OpCo: Operating Company
PCU: Photo Conductor Unit
PP: Production Printing
SE: Service Engineer
SKU: Stock Keeping Unit
SLA: Service Level Agreement
SMA: Simple Moving Average
1. Introduction

This chapter presents a description of Ricoh Netherlands which is a multinational that focuses on office solutions for businesses concerning document management. The products they offer as part of these solutions consist of printers, networking hardware, projectors and software. Beside products, Ricoh Netherlands also offers several services as part of these solutions.

The first section will briefly discuss Ricoh Netherlands, followed by a discussion of the initial problem considered in this research in section 1.2. In section 1.3 a problem overview is described, after which the outline of this research is presented in section 1.4.

1.1. Ricoh Netherlands

The services Ricoh Netherlands offers consist of, among others, the after sales maintenance of machines that are either leased or bought by their customers. These machines consist of different components that experience a certain failure rate. Ricoh Netherlands has contracted agreements on the maximum response and fix times with customers that lease equipment. These service level agreements (SLA) are part of the contract that the customer can engage in and for a large part these determine the contract prices. Not meeting these target service levels can sometimes lead to penalty costs and in the long run could even cause Ricoh to lose its customers due to customer dissatisfaction. The goal of the after sales service system of Ricoh Netherlands is meeting the SLAs it has with its customers.

Ricoh Netherlands is divided into six business units. The business unit responsible for the after sales service system is Order to Operations. Figure 1 depicts the seven departments that are part of the Order to Operations unit. To be able to manage the total stock value in an integral way, the department of Supply Chain Management carries responsibility for every physical asset owned by Ricoh Netherlands, including complete machines and service parts. The service
engineers who are part of the after sales service system are under supervision by the department of Hardware & Inbox Solutions. The department of Operations Planning & Monitoring is responsible for planning service engineers and service parts based on incoming service requests.

1.2. Research trigger

This research focuses on the after sales service system of Ricoh Netherlands that provides corrective maintenance services for installed systems that experience failure. Performing maintenance on installed machines sometimes requires service parts. In recent years the service part inventory at the European operating companies (OpCo’s) has received more attention from Ricoh Europe, resulting in their desire for lowering the inventory positions. Management at Ricoh Netherlands is therefore interested in finding out what the consequences are of lowering the inventory. Figure 2 shows the situation with regard to service parts management over a period of 7 months. The month on hand (MoH) indicates the ratio of the monthly demand for service parts and the average service part inventory position during a month, both expressed as relative cost figures. The average inventory position is calculated by taking the average of the starting and ending inventory positions during a month. The MoH shows that at the start of 2014, inventory was three times higher than demand, suggesting service part inventory could be managed more efficiently. The problem Ricoh faces is that inventory management is not based on informed decision making and that the effects of inventory levels on customer service and supply chain costs are unclear. Therefore Ricoh Netherlands is interested in finding out what the effects of lowering the service part inventory levels are on the supply chain costs and the performance levels. The problem described in this section serves as the basis of this research.

![Figure 2. Service part inventory management at Ricoh.](image-url)
1.3. Problem overview

The after sales service system is characterized by service engineers that are sent to customers to perform corrective maintenance on installed machines. The service parts that are sometimes required are made available to the service engineers at fieldstock locations. These consist of the cars with which the service engineers visit customers and non-moving stock locations in the field at which service parts are stored. Currently Ricoh Netherlands employs about 350 field service engineers that service 479 different models, representing almost 110,000 installed machines. These machines are leased by almost 13,000 billable customers producing a total of 9 billion prints per year. Several problems can be distinguished when investigating the high inventory investment at Ricoh discussed in section 1.2.

(1) Currently, inventory levels at the fieldstock locations are determined without the use of any centrally determined guidelines. Service engineers are responsible for determining the inventory at the fieldstock locations and they have complete autonomy with regard to this. They are responsible for making sure there is enough stock so that they always have the right service parts when they need them. The performance measures most important to the customer of an after sales service system are described in the SLAs. Although supply chain costs are important to Ricoh, the service levels are most important to the customer since these directly affect them. Because these relate to target response and repair times, meeting the service levels is not only dependent on inventory management but also on other factors such as the availability of a service engineer. Therefore, the primary key performance indicator (KPI) regarding inventory management is the number of visits during which an engineer did not have the correct service part(s) when needed. In that respect, the financial value of the service parts kept in inventory is a secondary KPI. Not having the required part causes a return visit and additional costs regarding wage and transportation costs. When a return is caused by not having the required service part it is called a return to fit parts activity. Other reasons for a return visit, such as the lack of knowledge on the part of the service engineer or not having had the proper training to service the machine, are registered separate from the return to fit parts. Because these reasons do not relate to inventory management they are excluded from this research. The best method of preventing return to fit parts activities is the maximization of the inventory levels and thereby the service part availability. In practice this means service engineers want to make sure they do not fall short on service parts and therefore stock up on service parts they might not really need. This represents a problem as it can cause redundant service part inventory. In the past some engineers have complained about not having enough room to stock the
service parts they need. This is related to both the sizes of the parts and the inventory levels, illustrating the need for guidelines which enable informed service part inventory decision making.

(2) There is a high uncertainty with regard to service part demand in advance of a customer visit. When a customer reports a problem there often is no information available about which service part(s) might be needed. This makes it impossible to know what service parts a service engineer should bring when visiting a customer for the first time to perform maintenance.

(3) Another problem that causes demand fluctuations is the presence of seasonality in the demand pattern. A technical malfunction called static build-up, which is caused by low temperatures and low humidity, causes the process of attracting toner to the drum to be disrupted during the winter period. This results in an increase in the failure rates of photoconductor units (PCUs) and two of its main components; the charge roller and the drum. The fluctuations in service part demand caused by seasonality can be quite large according to interviews conducted at the department of Hardware & Inbox Solutions and there are currently no mechanisms in place to deal with these fluctuations. Because service engineers have autonomy with regard to the inventory levels, they have to decide themselves on how to adapt to these fluctuations. This requires them to evaluate and update the inventory levels to match any changes in demand to ensure that stockout does not occur when demand arises.

(4) Over the years, many service engineers have acquired a wide range of skills, enabling them to service many different product families (which are groups of technically similar machines), thus allowing the resource planning department a lot of flexibility in their planning behaviour. Every product family requires specific service parts. It is the management’s belief that as some service engineers do not service certain product families they are trained on, they carry unnecessary inventory with them. Currently, there is no policy in place to manage or control the number of product families a service engineer services, thus allowing this problem to escalate.

(5) Another problem that contributes to the high inventory levels is the incorrect registration of inventory changes in the information system. Although this might contribute to the inventory problems and therefore should be dealt with by giving additional training on correct inventory registration, it does not seem to be the main problem. Correct registration of service part inventory changes is necessary regardless of whether inventory is correctly management or not.
In summary, there are five problems related to inventory management:

(1) lack of central fieldstock management
(2) demand uncertainty due to insufficient problem determination
(3) demand fluctuations due to seasonality
(4) skill set distribution
(5) incorrect part registration

Because the main reason for conducting this research is the high inventory investment at Ricoh Netherlands and the problem overview showed that the lack of central fieldstock management seems to be the main underlying reason for this, the topic of this research is service part inventory management.

1.4. Report Outline
This research follows the problem solving cycle presented by van Aken (2007). This cycle consists of determining a clear problem definition, analysing the problem, designing a solution, applying the solution to the problem and finally evaluating the results of applying it. The problem definition is given in the previous section of this chapter. In chapter 2 the research design is described, consisting of a literature review, the research assignment, the research questions formulated to support execution of the assignment and a demarcation of the research scope. Chapter 3 describes a detailed analysis of Ricoh Netherlands, which consists of a description of the service part distribution network and the demand fulfilment process, followed by an analysis of the inventory situation. Here the service part sizes and the demand fluctuations are also investigated. In chapter 4 the conceptual and mathematical model are described. This includes a discussion of the performance measure considered in this research. Chapter 5 discusses how demand fluctuations will be considered, followed by chapter 6 in which the model is tested using a case study at Ricoh. In chapter 7 the implementation plan for this model is described and the conclusions and recommendations are discussed in chapter 8.

1.5. Conclusion
In this chapter the inventory problems Ricoh is currently dealing with are discussed. The most important problem was found to be the lack of decision making guidelines. Designing a methodology which can provide insight into the relation between inventory management and cost and service level performance can therefore be useful to Ricoh. In chapter 2 a literature study is conducted to gain insight into the current body of literature on this subject.
2. Research Design

Analysis of the service part inventory situation at Ricoh identified the lack of centralized inventory management as the main cause for the height of the inventory levels. This has resulted in unguided decision making on inventory levels with regard to service level performance and costs. Seasonality and the storage capacity of the fieldstock locations are issues that are of influence on the inventory management problem and therefore worth considering when determining optimal inventory levels. Therefore, section 2.1 contains a literature review on service part inventory management. The research assignment is discussed in section 2.2, including the research questions and the research scope.

2.1. Literature review

2.1.1. Service part inventory management

There is a large contribution of models focusing on inventory management, one of those being Kranenburg (2006), which forms the basis for several other papers. Kranenburg (2006) discusses a fast method to determine the service part base stock levels for a system subject to aggregate mean waiting time constraints. Due to modifications by van Sommeren (2007) and later by Rijk (2007) the model considers a first time fix service level measure and also a maximum carstock capacity based on the number of items in stock.

Earlier research conducted at Ricoh is that of Breure (2007), who analysed the service part inventory management but focused only on carstock inventory. This is a shortcoming compared to Kranenburg (2006), who also considers the exchange of service parts between fieldstock locations. The omission of lockerpoints causes parts that are used by several different service engineers to be stored at each of their carstocks, when stock pooling at a locker point would have been a better solution, especially for high priced items with high storage costs.

2.1.2. Research opportunities

Based on the gaps found in the literature on service part inventory management and the problems found at Ricoh, three research opportunities can be identified: (1) demand fluctuations, (2) skill distribution and (3) service part size.

Demand fluctuations

As mentioned, seasonality is causing demand to fluctuate over time. Most literature on seasonality focuses on the aspect of forecasting, as opposed to the effect of seasonality on inventory management. Research on seasonality shows it can have a detrimental effect on
forecasting the demand pattern (Mitchell & Niederhausen, 2010). In their paper Mitchell & Niederhausen (2010) stress the importance of adequate inventory management when experiencing intermittent demand and seasonality, by means of explicit order triggers instead of those implicitly present in common base stock policies. The analysis of demand fluctuations can therefore be an important aspect of designing a comprehensive inventory management tool. However, in the context of service part inventory management, research on demand fluctuations due to seasonality is very scarce. In his inventory model, Kranenburg (2006) forecasts demand by using the average demand during the previous year. This neglects any fluctuations in the demand pattern and possible consequences for over or under estimation of the calculated base stock levels. Although Breure (2007) paid a lot of attention to the method of demand forecasting, seasonality was not included in the analysis. This suggests room for further research on considering seasonality when determining base stock inventory levels. Especially focusing on how to deal with updating the inventory levels to account for periodic demand fluctuations can prove useful.

**Skill distribution**

Another important gap found in the body of research on service parts distribution networks, is the inclusion of resource capacity of the engineer workforce. The research by van Houdt (2008) considered the skill distribution in isolation and was conducted at Ricoh. As van Houdt (2008) showed, from the perspective of SLA performance the skill distribution (which engineers are trained to service which product families) does not need to be exhaustive. In the contrary, by accurately assigning skills to engineers the average number of skills per engineer can be greatly decreased without lowering the SLA performance significantly. The added benefit of this would be a reduction in the range of service parts a service engineer has to keep in stock. This benefit was never proven and might suggest room for further research.

**Service part size**

The capacity restriction caused by the limited storage space at the fieldstock locations is not mentioned in any of the literature found on service part inventory management. Rijk (2007) does consider the capacity restriction in the form of the number of items that a carstock can hold, but does not consider the actual sizes of service parts. Rijk (2007) bases the capacity restrictions on the number of items a carstock contains at the moment of conducting the analysis. Because this does not consider the size differences between service parts, a possible extension of his research is the application of actual volumetric properties.
2.2. Research Assignment

In section 2.1, the literature on service part inventory management was discussed. Three research opportunities were found and based on these opportunities and the problem overview presented in section 1.3, a research assignment is formulated and discussed in this section.

The research by van Houdt (2008) showed the difficulties of implementing a new skill distribution. Furthermore, improved inventory management would still be required in order for inventory levels to be adequately determined, given the skill set a service engineer has. In other words, redistributing the skills would not solve the problem of not having clear guidelines to control inventory management. Therefore, the main subject of this research is service part inventory management and Ricoh is interested in finding out how the inventory levels influence service level performance and supply chain costs. The costs and service level are the two main performance drivers for this research. The research assignment is:

"Develop a tool to determine the optimal inventory levels and supply chain costs given a desired service level taking into account storage capacity restrictions for a service part distribution system with dynamic and static fieldstock locations."

2.2.1. Research Questions

Based on the research assignment several research questions have been stated. Because some service engineers have complained about not having enough room to stock the service parts they feel they need, a relevant topic to consider when determining base stock inventory levels is storage capacity. The literature review showed that research on this topic in the context of service part inventory management is sparse. As demand changes and fluctuations are present at Ricoh, service part inventory management should be able to deal with that by adjusting the fieldstock inventory levels when necessary. As previous research did not mention this, one of the research questions will focus on determining how the tool should be used with regard to updating the inventory levels, considering the effects on performance and costs. This leads to the following questions:

1. What are the performance and cost measures considered in the model?
2. How should the optimal fieldstock inventory levels be determined?
3. How should storage capacity restrictions be considered when determining the fieldstock inventory levels?
4. In case demand fluctuates over time, how should the tool be used to deal with this, when applying the tool on real-life data? And how does this influence cost and service level performance?
2.2.2. Research Scope

The scope within which this research is executed is discussed next. This includes giving a clear definition of the service parts that are considered in this research, explaining the key performance indicator used in this research and discussing the kind of maintenance which is considered.

Product Categorization

Figure 3 depicts the different types of products that Ricoh owns or sells. Hardware and software products refer to complete products bought or leased by the customer, either separate or as part of a solution, and are irrelevant for maintenance activities. Consumables are either items a printer uses during operation such as cartridges, or products that engineers use (instead of install) to perform repairs such as oil, cloths and gloves. Because this latter group is consumed over a longer period of time and cannot be attributed to a single service visit and cartridges are held on stock by the customer, all consumables are placed outside the scope of this research. Service engineers all have a tool box with a standardized set of tools. They are responsible for having the proper tools at their disposal when needed. Tools are not consumed the way service parts are and their ownership is not registered. The machines have a modular design, which makes the available tools (52 tools in total) rather small and general. Besides basic tools such as screwdrivers and a vacuum cleaner no tools exist which are specifically needed for a certain type of machine. Furthermore, according to sources within the Hardware & Inbox Solutions department at Ricoh, the number of return visits caused by not having the proper tools is negligible and confirming this, is the fact that it is not possible to register this type of return visit in the system. Therefore, tools are placed outside the scope of this research. Customer goods are also excluded from the analysis. Customer goods are service parts which are ordered and installed by the customers themselves and therefore do not hold any relation to the service part demand that occurs during the maintenance activities considered in this research. Finally, the service parts consumed by the engineer represent the set of service parts used for the analysis in.
Corrective and preventive maintenance

This research aims to optimize service part inventory management for corrective maintenance. Demand that occurs due to corrective maintenance is almost always instigated by a machine failure reported by a customer. The reason for performing preventive maintenance on a component or machine usually is that the life expectancy of that component has been reached. In the past the decision to perform preventive maintenance was made when a service engineer found it to be necessary while he was already present at the customer. In that sense, any demand caused by preventive maintenance was still unplanned and is therefore comparable to demand caused by corrective maintenance from the viewpoint of inventory management. Because currently no planned preventive maintenance is executed by Ricoh and the preventive maintenance performed in the past constituted less than 10% of total service parts demand experienced during 2011 until 2013, this fraction of demand is regarded as demand due to corrective maintenance. This is to make sure all demand is considered and none is lost.

Key performance indicators

The main KPI concerning service part inventory management as used by Ricoh is the return to fit parts rate. This measure is equal to the number of visits during which an engineer did not have the required service part with him, divided by the total number of service visits the engineer performed:

\[
\text{Return to fit parts} = \frac{\text{# of visits during which a required part was not available}}{\text{total # of visits}}
\]

Because not every service visit requires service parts, the stockout rate as used in this research is defined as the number of required service parts which an engineer did not have with him, divided by the total number of service parts which that engineer needed, effectively changing the measure to only consider service parts:

\[
\text{Stockout rate} = \frac{\text{# of service parts that were needed but not available}}{\text{total # of service parts that were required}}
\]

The stockout rate will allow for a more focused view on inventory management. The opposite of the stockout rate is the fill rate. In this research this is defined as: fill rate = 1 - stockout rate.

Region and service engineer selection

Ricoh considers four different regions in the Netherlands; North-West, North-East, South-West and South-East. Each service engineer operates within one of these regions. Furthermore, two
types of printers are distinguished; printers that print at a rate of 60 prints per minute or less are categorized as Office Printing (OP) and printers that can print at a rate of over 60 prints per minute are categorized as Production Printing (PP). In general OP machines are used by companies that need to print to support their core business whereas PP machines are used by companies for who printing is their core business. The service engineers that perform maintenance are categorized based on these two types of machines. Beside these two types of engineers, there are other types of engineers, some of whom also perform maintenance occasionally. Appendix A provides a more detailed description of the different types and also presents an analysis of the stockout rate performance of the different types of service engineers. This analysis shows that OP engineers experienced most of the service parts demand and also had the highest average stockout rate compared to the other engineers, making it the most interesting group with regard to inventory management. Because the South East region is the region with the highest service part demand, OP engineers operating in the South East region are chosen as the main focus in this research. There are currently 52 OP engineers active in the South East region. The data used in this research was collected from the 1st of January 2011 until the 31st of December 2013.

Service Strategy

Although different service strategies are possible, this research considers the current demand fulfilment strategy in place at Ricoh. This strategy makes use of decentralized fieldstock locations from where service part demand from many different customers can be fulfilled, which are replenished by a central warehouse. Another service strategy might be the replacement of the entire machines when a breakdown occurs and repairing this machine in a centralized repair location. However, because this would require a completely different after sales service system with regard to the type of products kept in inventory and the way in which transportation is done, this option is not considered.

2.3. Conclusion

This chapter started with a discussion of the current body of literature. Based on this the research assignment was stated, which is to develop a tool that is able to determine the base stock levels for the service part distribution network at Ricoh. This research will also include an analysis of the influence of demand fluctuations on application of the designed tool. Based on the research assignment and the research scope a detailed analysis of the current situation at Ricoh is presented in chapter 3.
3. Detailed analysis Ricoh

In this chapter the current situation regarding inventory management and service part demand fulfilment at case study company Ricoh is discussed. In section 3.1 the service part distribution network is discussed. Based on this distribution network the after sales service system is discussed in section 3.2, focusing on the SLA’s Ricoh has with its customers and the process by which demand is fulfilled. In section 3.3 a detailed service part inventory analysis is presented, consisting of a discussion of the recent stockout performance at Ricoh and the analysis of service part demand. Section 3.4 concludes with a demarcation of the distribution network and the demand fulfilment options considered in the remainder of this research.

3.1. Service part distribution network

The fieldstock locations in which service part are stored, are depicted in figure 4, showing the distribution network of service parts for Ricoh Netherlands. The arrows indicate the flow of service parts through the system. The European Spare Parts Centre (ESPC) at Schiphol-Rijk acts as a central warehouse for Ricoh Europe and replenishes the regional warehouses located throughout Europe. Because it is located in the Netherlands, it also functions as a regional warehouse for Ricoh Netherlands. Because the ESPC functions autonomously from Ricoh Netherlands, both financially and with respect to inventory management, inventory management at the central warehouse is outside of the scope of this research. With regard to replenishment of the fieldstock locations, this means it is implicitly assumed that the central warehouse has ample stock and an order placed there can always be instantly fulfilled. In general the ESPC is able to instantly ship 97% of the orders placed by Ricoh Netherlands. There are three kinds of stock kept at fieldstock locations under control by Ricoh Netherlands. Carstock refers to the service parts stored in the trunk of a service vehicle with which a service engineer visits a customer. Lockerstock consists of those service parts that are stored at a

![Figure 4. Service parts distribution network at Ricoh](image)
lockerstock location (also referred to as a lockerpoint). These are static storage locations located throughout the country, from where field service engineers can retrieve service parts they do not have available in their carstock. Customerstock consists of service parts stored at onsite stock locations at customers. Whether a customer has customerstock on site depends on the amount of service parts that are required by the installed base at that customer. There are only a few customers that have customerstock on location and when this is the case, any demand at that customer is fulfilled from this stock location. For customers that do not own any customerstock, demand is fulfilled by the carstock of the visiting service engineer. Because most customers that own customerstock also have dedicated service engineers on site that do not own any carstock, carstock and customerstock can both be viewed as the first line of order fulfillment (this will be explained further in section 3.3.2). Fieldstock consists of the total amount of service parts in the form of carstock, lockerstock and customerstock. All fieldstocks are replenished by the ESPC. Service parts can also be exchanged between different carstocks or between the carstock of a service engineer and a locker point. Service part replenishment can be accelerated, called an emergency replenishment, which is either by regular transportation or by delivery through a dedicated courier service.

3.2. After sales service system

3.2.1. Service Level Agreements

The after sales services system at Ricoh serves the purpose of ensuring that the service levels agreed upon with a customer are met. These service levels are formulated in SLAs and consist of three target levels:

- The maximum response time, which is the moment at which a customer reports a problem until the moment the process of fixing the problem is initiated;
- The maximum time to fix or downtime, which is equal to the response time plus the time it takes to fix the problem;
- Minimum availability, which is the percentage of time during which the machine is available for use. Targets for this measure are usually set for the entire population of machines installed at a customer and only rarely set for individual machines.

These three service measures are interdependent; as the time to fix goes down, the lower bound on the expected availability goes up. Therefore the SLAs regarding these parameters are also dependent. The service parts necessary to be able to service customers according to the SLAs can be fulfilled in different ways. This process of service part demand fulfilment is discussed next.
Corrective maintenance is always instigated by a service request. This is the reporting of a defect or problem with one of Ricoh's machines by a customer. Ricoh then plans a service visit, which is a service engineer visiting a customer to perform a repair. If during the first visit demand for a service part occurs there are five options by which this demand can be fulfilled. These options are considered sequentially as depicted in figure 5. It is important to note that it is rarely known what service part(s) might be needed during a service visit before the engineer visits the customer. Due to this, the maximum response time is only related to planning efficiency and planning capacity; service part availability does not influence the response time of a first visit.

1. If possible, the service engineer uses a service part from his own carstock or the customerstock available at the customer to fulfil demand. This does not incur any extra costs, i.e. the service parts are immediately available to the service engineer so this does not take any extra time.

2. If possible, the service engineer visits the nearest lockerpoint to acquire the service part. This only occurs when the required service part is available at the lockerpoint and the distance between the customer and the lockerpoint is small enough to ensure that the visit and the repair time can occur within the fix time agreed upon in the SLA.

3. If possible, the service engineer meets up with another service engineer from whose carstock he acquires the service part. This will require the service engineer who requires the service part to contact someone who can check the other carstocks and find out if the distance between the carstocks is small enough to ensure that the service part exchange and the repair time stay within the fix time agreed upon in the SLA.

4. In case breaching the SLA belonging to the defective machine would result in excessive penalty costs (for instance due to the fact that the machine is of vital importance to the core business of the customer), a courier service can be used to immediately transport the required service part from the ESPC to the customer.
5. The service engineer does not repair the problem and instead a return visit is planned. This return visit is not necessarily performed by the same service engineer. To make sure the service part will be present as soon as possible an emergency delivery from the ESPC is executed, which means the moment of shipment is accelerated in comparison to a regular replenishment.

Using customerstock would only be useful for locations with a relatively high number of installed machines. This is exactly what Ricoh is already doing for larger customers that have multiple machines in operation at a location. The customers that own customerstock have dedicated engineers on location called onsite engineers (Appendix A). Therefore it rarely happens that OP engineers visit those customers. Because the onsite engineers have a very low overall stockout rate, they have already been placed outside the scope of this research. Customerstock locations will therefore not be considered in the remainder of this research. In case research on the customerstocks is necessary at a later moment, the model developed in this research will still be applicable due to the fact that customerstocks can be viewed as a special case of carstocks. The difference is that in the case of customerstock the inventory can only be used for a specific customer (dedicated inventory), whereas in the case of carstock the stock can be used to fulfil demand for any customer.

Option 3 considers the exchange of service parts between two carstocks. This will however not take place if the distance between the service engineers is too large. Because the locations of the carstocks are dynamic, this mainly depends on coincidence. It is therefore difficult to determine which carstocks exchange inventory and which do not. Currently it is not possible to find out how often this type of inventory exchange occurs, but according to sources within Ricoh this only occurs occasionally. Therefore, taking this type of fulfilment into account would not contribute much and it will not be considered in this research.

Option 4 considers immediately shipping a service part to the customer by courier, when service parts are required for a repair. This is a very expensive way to fulfil demand and this is mainly used when the machine that requires maintenance is of vital importance to the core business of the customer. As mentioned before those customers generally use PP machines which have already been placed outside the scope of this research in the previous section. The use of courier services for OP machines is very unlikely as most customers usually have more than one printer available, which allows them to divert to another printer in case of emergency. Therefore those customers usually do not require instant repair and they are satisfied knowing Ricoh is taking care of the problem even if repair occurs 1 or 2 days later. Because delivery by courier is highly unlikely for OP machines, this form of demand fulfilment is placed outside the scope of this research.
3.3. Service part inventory analysis

The main focus of this research is the current lack of central fieldstock management at Ricoh. This section contains an analysis of the extent and consequences of this problem. The two issues recognized as gaps in the literature regarding service part inventory management are the characteristics of the service parts and fluctuations in the service parts demand pattern. These issues are analysed in detail for the case of Ricoh starting with an analysis of the stockout rate and inventory investment.

3.3.1. Lack of central fieldstock management

It is believed that service engineers might keep unnecessary service parts on stock due to the return to fit parts performance measure. To find out what the relation between the inventory quantities and the performance is, the carstock investment for the South East OP engineers is plotted against the stockout rates achieved by those engineers (figure 6). The normalized investment is calculated as the fraction of the highest measured carstock investment for any one service engineer. The data on the inventory investment per engineer was collected at the 1st of January 2014 and the stockout rate performance is calculated based on data from the 1st of July 2013 until the 31st of December 2013. A period of half a year is chosen to ensure that both measures can be compared. The average stockout rate for OP engineers was 21.06% and the graph shows that those service engineers that have higher inventory investments do not necessarily achieve better fill rate performance. Therefore, insight into the relationship between the fieldstock inventory levels and the service levels can guide inventory management and allow for better inventory control. In the past some engineers have complained about not having enough room in their car to stock the service parts they need. Some parts are known to be too big to store in a carstock and other parts can only be stored in small numbers due to their size.

![Figure 6. Scatterplot of the stockout rate-carstock investment for the South East OP Engineers](image-url)
The solution for this might be to store those parts in locker points or at customer locations. Management on what parts to store at the locker points is however not well integrated with carstock management, because two different parties are responsible for their contents. This causes a mismatch between the parts that are stocked in locker points and those that are stocked in cars or at customer locations. The underlying reason for this seems to be the lack of a clear policy on which service parts to stock at the lockers. This causes expensive parts to be stored more decentralized in carstocks where centralized stocking in lockerpoints could reduce inventory holding costs through stock pooling benefits. Figure 7 shows a scatterplot of the size and the relative value (compared to the most expensive service part) for the 4377 SKUs that experienced demand during the 1st of January 2011 until the 31st of December 2013. It shows that some of the largest service parts also have the highest cost prices. For instance, the service parts that are worth more than 30 percent of the most expensive service part and are larger than 20,000 cm³ experienced an average demand of 2 per year. This shows that using lockerpoints might provide significant cost advantages for those service parts from the perspective of stock pooling. Total inventory for larger or more expensive parts can then be lowered by storing those parts more centralized in locker points.

![Figure 7. Scatterplot of the cost price and volume of 4377 SKUs](image)

### 3.3.2. Demand

Data from the 1st of January 2011 until the 31st of December 2013 is used to investigate the demand. Four distinct service part categories are considered; charge rollers, drums, PCUs (parts which are thought to experience seasonality) and “normal service parts” (the category that represents the rest of the service parts). Figure 8 depicts the demand during 2011-13 for each
of the four categories. The figure shows that even the normal service parts seem to experience seasonality and that there is a possible trend for all three of the seasonal service part categories. When comparing the 2011/12 winter period to the 2012/13 winter period, demand for drums has decreased whereas demand for the PCUs and the charge rollers has increased. Further inquiry into this phenomenon, suggests the most likely reason for this was the fact that operational guidelines for the service engineers changed. Before and during the winter of 2011/12 instructions were to try to repair the PCU if possible, which meant replacing its components (the drum and the charge roller). Because this takes more time than complete replacement of the PCU, during the more busy winter of 2012/13 instructions were to replace PCUs completely. Therefore, the presence of a real trend in either one of the service part categories is deemed unlikely, especially because the normal service parts do not show any trend either.

To investigate to what extent seasonality is present in service part demand, seasonal indices are calculated. Because the four previously mentioned service part categories showed seasonality in different magnitudes, seasonal indices are calculated on aggregate for each service part category. Figure 8 shows that monthly demand has a high variation. Therefore seasonal indices are calculated per quarter. Because the seasonal pattern is caused by temperature changes, the time periods are chosen to match these. Officially, winter in the Netherlands lasts from the 21st of December until the 21st of March. Based on information about the temperature in the Netherlands during 2011, 2012 and 2013 (source: knmi.nl), the lowest temperatures were reached halfway during the winter (start of February). Therefore the quarterly time periods are matched with the seasons, resulting in four quarterly periods starting at the 21st of March, the 21st of June, the 21st of September and the 21st of December. In total demand data for 11 quarterly periods is available. The indices are calculated by dividing the quarterly demand for each quarter by the average quarterly demand during the period from 2011 until 2013 and are depicted in figure 9. As mentioned before, the seasonal effect during the winter of 2011/12 and the winter of 2012/13 differed a lot and figure 9 confirms this. The normal parts show a very small seasonal effect compared to the seasonal effects observed for the other three seasonal service part categories. The graph also shows that for the drums and the charge rollers high demand does not occur during the same season every year. For the charge rollers and the PCUs, low demand does not always occur during summer. These findings show that the seasonality effects shift from year to year causing peaks and dips to occur during different seasons. This causes a more consistent seasonal pattern when considering half year periods by grouping fall with winter and spring with summer. This suggests that consideration of the (seasonal) demand pattern when determining the base stock levels can prove useful to comprehensively manage inventory at the fieldstock locations.
3.4. Conclusion

This chapter covered the selection of service engineers on which this research focuses. Furthermore the uncertainty in demand and the importance of service part characteristics were discussed, concluding they both have an impact on service part inventory management at Ricoh. Based on this analysis the system considered hereafter is now presented. The three demand fulfilment options considered in this research are (figure 10):

1. fulfilment by a carstock
2. fulfilment by a lockerpoint
3. fulfilment at a later moment – i.e. a return visit is planned and the service part is ordered
Which option works best differs per service part and depends on the individual characteristics of that service part. For large and expensive SKUs, stock pooling in the form of more centralized storage in a lockerpoint can provide benefits related to holding costs and capacity use. For cheaper and smaller SKUs the cost of visiting a lockerpoint might not be worth the reduction in inventory costs, thus making it more cost efficient to store those items in the carstocks of service engineers.

The considered demand fulfilment options and the exclusion of customerstock result in the distribution network considered in the remainder of this research depicted in figure 11.

Based on the findings in this chapter the fieldstock inventory model designed in this research should be able to consider which demand fulfilment options are best for which service parts, while considering the associated supply chain costs and the overall service level performance. In chapter 4 the design of the fieldstock model is discussed.
4. Model description

This chapter describes the methodology designed to realize the research assignment. Section 4.1 starts with a description of the requirements the fieldstock model designed in this research should satisfy. Based on these requirements the use of existing models is discussed. Section 4.2 continues with a discussion of the performance measure used for the fieldstock model. This is followed by section 4.3 in which the model is described mathematically. Section 4.4 discusses the language in which the fieldstock model is programmed, followed by section 4.5 which presents the conclusion of the chapter.

4.1. Model choice

The tool designed in this chapter is required to determine inventory base stock levels by considering which of the demand fulfilment options discussed in chapter 3 is best for an SKU. This consideration has to be made while satisfying the target service levels and not exceeding the storage capacity of the fieldstock locations. The goal of the model is to achieve minimum supply chain costs regarding transportation and inventory while satisfying these restrictions.

Based on the literature review on service part inventory management presented in section 2.1, the model presented in the paper by Kranenburg (2006) is found to match the aforementioned requirements. Therefore this model will serve as the basis for the fieldstock model developed in this research. The following assumptions belong to this model:

- Item failure has the same effect on a machine for all items
- Demand is Poisson distributed
- Infinite service part supply from the central warehouse
- One-for-one replenishment policy
- Replenishment lead times are independent
- Transportation times and costs are constant
- Holding costs are charged over items in the replenishment pipeline

4.2. Adjustment of the model by Kranenburg

Kranenburg (2006) considered a different system from the one considered in this research and the differences are discussed next.

Only the carstocks experience direct customer demand. The lockerstocks do not experience any direct demand and only experience indirect demand from the carstocks connected to it. This happens when a carstock cannot fulfill demand.
Every fieldstock location is restricted by a maximum storage capacity. Due to the fact that the model presented in Kranenburg (2006) is based on stationary fieldstock locations, the distances between them is constant. In this research the distances between the carstocks and the lockerpoint vary over time depending on where service engineers are when demand occurs, i.e. at which customer they are. The assumption of constant distances is necessary to enable application of a time-based aggregate fill rate where lockerpoints can be used to fulfil demand within the first visit. Because the transportation times and costs from the carstocks to the lockerpoint are difficult to accurately acquire due to measurement faults, an average distance is assumed, resulting in constant transportation costs and time.

Directly from the assumption of constant transportation times, it follows that service engineers only visit the lockerpoint with the shortest transportation time. In real-life, service engineers are allowed to visit any of the 13 lockerstock locations in the country. To determine the demand experienced at a lockerpoint, inferences need to be made about which service engineers visit a lockerpoint to determine how much demand is allocated to that lockerpoint. This location-allocation problem is a well-covered topic in the existing literature, although most literature focuses on fixed demand locations. Benjaafar et al. (2008) consider a situation in which demand occurring at multiple geographically dispersed locations needs to be allocated to multiple fixed inventory locations. Based on their analysis they conclude that all demand originating at a single location should always be fulfilled by a single inventory location. In the current research the inventory locations are the carstocks which do not have fixed locations causing demand from a single demand source to be allocated to different inventory locations. To be able to allocate demand, it is therefore assumed that a service engineer visits the lockerpoint with the shortest travel time from his home. Service visits are planned based on, among others, the travel time between the then current location of a service engineer and the customer that requires service. Because the service engineer starts his day at home, visits tend to be planned as nearby to his home as possible, to avoid long travel distances. Assuming the most likely lockerpoint he will visit is the one nearest to his home is therefore reasonable and allows consideration of only one lockerpoint for each service engineer. Furthermore, because no historic data is available on which service engineers visited which lockerpoints, there is no way of determining these ‘links’ more accurately.

4.3. Performance measures
To determine an adequate service level measure for the fieldstock model designed in this research, several different common performance measures used in service part distribution networks are discussed. Another important aspect of determining an appropriate service level
measure is the aggregation levels at which targets are set. Both subjects are now discussed, after which a performance measure is chosen for this research.

**Item and system availability**

With regard to service level targets two main options can be distinguished. System availability refers to the uptime of a machine and most accurately represents the interests of customers (Boone, 2006). Customers are interested in a high availability of their machines, which results in service level targets being set for the *maximum down time* of a machine. This measure represents the amount of time during which a machine is not available to the customer and therefore depends on the availability of the service parts needed to repair a machine failure. In contrast, item availability focuses on the availability of individual SKUs.

In the current research, SLA targets are most commonly set on aggregate for all machines leased or owned by a single customer. When maintenance at a customer is always performed by the same service engineer, focusing on system availability is appropriate for managing the carstock of that service engineer. Because customers can be visited by different service engineers, using the overall system availability per customer is not useful when determining inventory base stock levels for individual service engineers. Because of this and the fact that service engineers are assessed on their individual return to fit parts performance, the fieldstock model presented in this research focuses on the item availability, aggregated on the level of the service engineer.

**Performance metrics**

The service level measure can be represented by several performance metrics (Elrod, Murray, & Bande, *A Review of Performance Metrics for Supply Chain Management*, 2013):

- Mean waiting time until repair; the average time the machine is not available to the customer when a breakdown occurs.
- Machine availability rate; this is the percentage of time during which the customer cannot use the machine.
- Item fill rate; the percentage of items required to fix a machine which are immediately available.

The *mean waiting time until repair* and the *machine availability rate* are both metrics which focus on the downtime of a machine. For the sake of service parts provisioning this downtime can be translated to the time waiting for parts. Kranenburg (2006) uses the aggregate mean waiting time service measure which uses the actual time it takes for demand to be fulfilled. Although the waiting time service measure could potentially represent the distances between the carstocks and the lockerstock locations and thereby accurately determine if the contracted SLAs are met, the application of this service level in this research is difficult due to two reasons:
- Repairs at a customer are not always done by the same service engineer causing service engineers to experience different kinds of SLA contracts (different customers have different fix times and response times). Therefore it is impossible to state when a service engineer can perform a repair within the agreed fix time and when it cannot; this varies depending on the SLA of the customer and the proximity of the service engineer to the lockerpoint in case an engineer finds out he needs a service part from a lockerpoint.

- The travel time between the fieldstock locations is not constant because the current network consists of carstocks that move within a certain area. As discussed this necessitates the use of an average distance to implement the waiting time service measure in the current network. Using average distances would make it impossible to accurately determine which customers are serviced within their SLAs and which are not, when visiting a lockerpoint.

The service measure used by Rijk (2007) is based on the *item fill rate* which focuses on the availability of parts regardless of the time it takes to fulfil demand. In his paper the time-based aggregate fill rate which focuses on the percentage of demand fulfilled within a certain period of time is used. In advance, it is determined whether a certain demand fulfilment method can fulfil demand within the required time or not. This measure does not take the exact service times into consideration, therefore ignoring the SLA performance. From a cost perspective this can however be justified. The main cost component of not being able to perform a first time fix is related to the return visit, which requires a service engineer to revisit the customer. Other costs related to not performing a first time fix can be caused by breaching the SLA. However, because breaching the SLA for OP machines hardly ever results in actual penalty costs (about 99% of the entitled reimbursements are never claimed), these costs are regarded as negligible compared to the costs of the return visit itself.

Because of these arguments the time-based aggregate fill rate as used by Rijk (2007) is used as the service measure for this research. This performance measure is adapted to focus on item availability on aggregate per service engineer.
4.4. Mathematical model

The following variables are used in the mathematical model.

**Decision variables:**

- $S_{i,j}$: Base stock level for service part $i$ at fieldstock $j$

**Dependent variables:**

- $\alpha_{i,j}(S_j)$: Fraction of demand for service part $i$ at carstock $j$, fulfilled by lockerstock $l$
- $\beta_{i,j}(S_j)$: Fraction of demand for service part $i$ at carstock $j$ fulfilled by carstock $j$
- $\beta_{i,j}^{em}(S_j)$: Fraction of demand for service part $i$ at carstock $j$ fulfilled by means of an emergency shipment resulting in a second visit at a later moment in time.
- $\beta_{i}^{obj}$: Target average first visit fill rate for carstock $j$
- $\beta_{i}^{total}(S_i)$: Total demand for service part $i$ at carstock $j$ fulfilled during the first visit
- $\bar{M}_{i,l}$: Total demand for service part $i$ at lockerpoint $l$ per unit time

**Input parameters:**

- $C$: Set of carstocks
- $C^{back}$: Costs incurred for sending service parts back to the central warehouse
- $C^{em}$: Cost of having to perform a second visit
- $C^{lock}$: Cost of picking a service part up at a lockerpoint
- $C^{reg}$: Cost of a regular replenishment
- $C^{SE}$: Hourly rate of service engineer
- $C^b$: Obsolescence cost per unit time for service part $i$
- $C^h_{i,j}$: Holding cost per unit time for service part $i$ stored at fieldstock $j$
- $C^o_{i}$: Opportunity cost per unit time for service part $i$
- $C^s_{i,j}$: Storage cost per unit time for service part $i$ stored at fieldstock $j$
- $I$: Set of service parts
- $J$: Set of fieldstock locations
- $l$: Lockerpoint
- $M_{i,j}$: Direct customer demand for service part $i$ at fieldstock $j$ per time unit
- $M_{j}$: Total daily demand at fieldstock $j$
- $P_i$: Value of service part $i$
- $t^{reg}$: Replenishment time from the central warehouse to a fieldstock location
- $V_i$: Size of service part $i$
- $V_{j}^{max}$: Maximum storage capacity of fieldstock $j$
- $x$: Percentage of value recovered when selling a service part back to the central warehouse

A **lockerpoint region** is defined as the area that consists of a set of $J$ fieldstock locations denoted by $j \in 1, ..., |J|$, which includes all the carstocks active in that area and the lockerpoint to which these carstocks are connected, i.e. the lockerpoint from where the service engineers can acquire service parts. The carstocks are denoted by $c \in C$ ($\subseteq J$) and the lockerstock is denoted by $l$ ($\in J$). The set of unique service parts or SKUs is denoted by $i \in I$. The average direct customer demand per unit time for SKU $i$ experienced at fieldstock location $j$ is assumed to be Poisson
distributed and is denoted by $M_{i,j}$. The total average demand experienced at fieldstock location $j$ is denoted by $M_j := \sum_{i \in I} M_{i,j}$ and $M_j > 0$. Every fieldstock location $j$ has a base stock policy $S_{i,j}$ for SKU $i$. The total average demand experienced at fieldstock location $j$ is denoted by $\sum_{i \in I} M_{i,j}$. Fieldstock locations receive a replenishment $t^{reg}$ time after the order is placed. The base stock levels of the fieldstock locations are restricted to a maximum capacity. The maximum capacity of fieldstock $j$ is denoted by $V_j^{max}$. Every item $i$ has a size of $V_i$.

**Optimization model**

The goal of the optimization model is to determine the base stock level $S_{i,j}$ for $j \in J$ while minimizing the total costs $C_i(S_i)$ (equation 1) for each service part $i$ and fieldstock $j$ subject to two main restrictions. The first restriction is the achievement of a target fill rate $\beta_{i}^{obj}$, for $j \in J \setminus l$ (equation 2). The performance of an engineer is based on the fill rate performance over all the SKUs he experiences demand for and the fill rate for each SKU is therefore weighted based on the demand rate per SKU. The second restriction is the storage capacity of the fieldstock locations (equation 3). Equation 2 and 3 can be in conflict when the storage restriction does not allow the target fill rate to be achieved. This is further discussed in section 4.4. The base stock levels $S_{i,j}$ can only take on positive integers and because the performance measures are fractions these can take on values between zero and one. This results in the following optimization problem:

$$\min \sum_{i \in I} \left( \sum_{j \in J} c_{i,j} S_{i,j} + \sum_{j \in J \setminus l} M_{i,j} \left( C^{reg} \beta_{i,j} (S_{i,j}) + C^{lock} \alpha_{i,j} (S_{i,j}) + C^{em} \beta_{i,j}^{em} (S_{i,j}) \right) \right)$$

subject to

$$\sum_{i \in I} \frac{M_{i,j}}{M_j} \beta_{i,j}^{total} (S_{i,j}) \geq \beta_{j}^{obj} \quad \forall j \in J \setminus l$$

$$\sum_{i \in I} V_i S_{i,j} \leq V_j^{max} \quad \forall j \in J$$

$$S_{i,j} \geq 0 \quad \forall j \in J$$

$$0 \leq \beta_{i,j}, \alpha_{i,j}, \beta_{i,j}^{em} \leq 1 \quad \forall j \in J$$

This optimization model is now discussed and explained in detail. First, the demand fulfilment options and the associated variables are explained, followed by an explanation of the overall performance measure, the cost function and the cost parameters.
Demand fulfilment

The demand fulfilment options are always considered according to a predefined order. Figure 12 graphically depicts these ways. It is important to note that the system is considered for each SKU $i \in I$ separately.

1. Demand is fulfilled by the carstock that experiences the demand. Because only carstocks experience direct customer demand, $M_{i,t} = 0$. The fraction of $M_{i,t}$ fulfilled directly by carstock $c$ is denoted by $\beta_{i,t}(S_{i,j})$.

2. If demand cannot be fulfilled by carstock $c$, it flows over to the lockerpoint connected to it. The fraction of demand for SKU $i$ at carstock $c$ fulfilled by lockerstock $l$ is denoted by $\alpha_{i,c,l}(S_{i,j})$. The total demand experienced at lockerpoint $l$ is denoted by $\tilde{M}_{i,l}$. The fraction of $\tilde{M}_{i,l}$ lockerpoint $l$ is able to fulfil is denoted by $\beta_{i,l}(S_{i,j})$.

3. For the demand for service part $i$ at carstock $c$ not fulfilled by carstock $c$ itself or the lockerpoint connected to it, an emergency order is placed at the central warehouse and a second visit is planned at a later moment in time. This fraction of demand is denoted by $\beta_{i,c}^{em}(S_{i,j})$.

To ensure no demand is lost, the following should hold for each item $i \in I$ and fieldstock $j \in J$:

$$\beta_{i,j}(S_i) + \alpha_{i,j,i}(S_i) + \beta_{i,j}^{em}(S_i) = 1 \quad (6)$$

In case demand is fulfilled from the carstock or the lockerstock location, the visit counts as fulfilment within the first visit because no return visit needs to be planned. In case demand is
fulfilled by means of an emergency shipment a return visit has to be planned. The total fraction of
demand for service part \( i \) at carstock \( c \) fulfilled during the first visit is denoted by:
\[
\beta^\text{total}_{i,c}(S_i) := \beta_{i,c}(S_i) + \alpha_{i,c}(S_i).
\]

**Cost parameters**

With regard to the supply chain costs, two main cost parameters are taken into account;
**holding costs** – which consist of opportunity, storage and obsolescence costs – and
**transportation costs.** As mentioned in section 4.2, penalty costs related to Ricoh breaching the
SLA are rarely incurred by customers. Therefore these are not considered. The total relevant
costs for service part \( i \) per time unit as depicted in equation 1, are denoted by \( C_i \):

\[
C_i(S_i) = \sum_{j \in j} C^h_{i,j} S_{i,j} + \sum_{j \in j/l} M_{i,j} \left( C^{\text{reg}} \beta_{i,j}(S_{i,j}) + C^{\text{lock}} \alpha_{i,j}(S_{i,j}) + C^{\text{em}} \rho_{i,j}(S_{i,j}) \right)
\]

(7)

For SKU \( i \) stored at fieldstock location \( j \), the holding cost per item per time unit is \( C^h_{i,j} := C^0_i + C^b_i + C^s_i \) with \( C^h_{i,j} > 0 \). The total inventory cost for item \( i \) at fieldstock location \( j \) per time unit is equal to \( \sum_{j \in j} C^h_{i,j} S_{i,j} \). Opportunity costs are costs incurred due to the investment of money with
which no profit can be made through other business ventures. Obsolescence occurs when a
service part becomes redundant because there are no longer any machines in operation that
require it or because the part has been replaced by a successor. This means the part could
become worthless over time. Storage cost refers to costs incurred for renting the inventory
location at which the part is stored. All three of these costs are incurred per unit time per item
in stock and the former two are proportional to the value of the item which is denoted by \( P_i \). The
storage cost is proportional to the size of the service part \( V_i \). To calculate these cost components
a predetermined cost factor is used. The opportunity costs are denoted by \( C^o_i := h P_i \), the
obsolescence costs are denoted by \( C^b_i := f P_i \) and the storage costs are denoted by \( C^s_i := g_j V_i \).

The transportation cost concerned with a regular shipment, an emergency shipment and
picking up service parts at the lockerpoint are denoted by \( C^{\text{reg}}, C^{\text{em}} \) and \( C^{\text{lock}} \), respectively.
These consist of total handling costs, vehicle related costs and labour costs. Because an
emergency shipment always coincides with a second visit that follows from not having a service
part on stock and visiting a lockerpoint consists of costs for regular replenishment plus
transportation costs from the lockerpoint to the carstock, the following holds: \( C^{\text{em}} \gg C^{\text{lock}} > C^{\text{reg}} \). The total costs for service part \( i \) per time unit related to demand fulfilled directly are equal
to \( \sum_{j \in j/l} M_{i,j} \left( C^{\text{reg}} \beta_{i,j}(S_{i,j}) \right) \), those related to demand fulfilled from a lockerpoint are equal to
\( \sum_{j \in j/l} M_{i,j} \left( C^{\text{lock}} \alpha_{i,j}(S_{i,j}) \right) \) and those related to emergency shipments are equal to
\( \sum_{j \in j/l} M_{i,j} \left( C^{\text{em}} \rho_{i,j}(S_{i,j}) \right) \).
As can be seen from equation 7, the service level measures $\beta_{t,c}, \alpha_{t,c,t}$ and $\beta_{t,c}^{em}$ are directly related to the cost performance of the model. How these service level measures are determined is described in the next section.

4.5. Procedure to solve the model

The optimization problem concerns a nonlinear integer problem (NIP). Solving this optimization problem requires finding the policy, i.e. the set of base stock levels $S_{t,j}$, $\forall i \in I, \forall j \in J$, that meets the restrictions of the model with minimal costs. To do so, the costs for any given set of base stock levels need to be calculated which requires the service level measures $\beta_{i,j}$, $\alpha_{i,j,t}$ and $\beta_{i,j}^{em}$ to be determined for $\forall i \in I, \forall j \in J$. Kranenburg (2006) describes both an exact and an approximate evaluation method to determine the service level measures. The exact method however tends to become intractable for real-life problems consisting of a large number of SKUs and locations. The total computation time actually grows exponentially with the number of fieldstock locations. To deal with this problem an approximate method is introduced. This method makes use of a decoupling algorithm. Kranenburg (2006) compared the approximate method with the exact method on their performance for several different network configurations containing between 0 and 5 warehouses and 50 SKUs. While costs were found to deviate by only 2.02%, the approximate method achieved an average computation time of only 30 milliseconds, opposed to the exact method averaging at 163 seconds. Considering the fact that the number of warehouses in this research is already 53 and more than 2500 SKUs experienced demand during 2013, use of the approximate method is justified. Next the base stock policy with as low as possible costs needs to be determined. Kranenburg (2006) states that for the integer-valued decision variables and non-linear constraints, no other optimization procedures exist than enumerative methods. Again these methods become intractable for real-life problems consisting of a large number of SKUs and locations. Therefore a solving algorithm is used which is based on an algorithm that is able to find a ‘close-to-optimal’ solution by iteratively increasing the base stock levels for all SKUs and all fieldstock locations by one, based on cost considerations. Both the decoupling algorithm and the solving algorithm are discussed next.

Decoupling algorithm

The decoupling algorithm focuses on determining the demand flows between the carstocks and the lockerstock location with the goal of decoupling them from each other so that they can be analysed in isolation. This allows determining the service level measures and the cost
performance for any known policy and known direct customer demand equal to $M_{i,j}$, $\forall i \in I$, $\forall j \in J$. A detailed description of the decoupling algorithm is given in Appendix B.

**Solving algorithm**

The solving algorithm is able to determine a feasible base stock level configuration given the optimization problem described in section 4.3. Kranenburg (2006) evaluates every SKU separately, relying on the fact that inventory management for the different SKUs is independent of each another. Because this research takes storage capacity into account, this independence is no longer applicable. Rijk (2007) considered the capacity of a fieldstock by assuming it was only able to store a maximum number of items at that fieldstock. This caused the separate evaluation of SKUs to be suboptimal because the fieldstock locations might be filled to their capacity by SKUs that provide lower cost benefits than other SKUs would have achieved. Rijk (2007) therefore considered all SKUs simultaneously when determining the base stock levels. This research applies a similar approach.

The algorithm is a greedy heuristic and consists of the following three steps: (1) set the base stock levels to zero, (2) determine the base stock levels with the lowest total supply chain costs and (3) adjust the base stock levels in order for the target fill rate to be met. These three steps are graphically depicted in figure 13 and explained next. The mathematical representation of the solving algorithm is presented in Appendix B.

![Figure 13. Solving algorithm](image)

**Step 1**

The first step consists of setting the base stock levels $S_{i,j}$, $\forall i \in I$, $\forall j \in J$ to zero.

**Step 2**

For each combination of SKU $i \in I$ and fieldstock location $j \in J$, the base stock levels $S_{i,j}$ are increased by one, starting with the base stock level that provides the biggest cost decrease. The base stock levels are increased until no further cost advantages can be achieved. When adding
an item to a fieldstock, the choice between a smaller SKU and a larger SKU, both offering the same cost benefits, should be based on the cost benefit per unit volume. This way, the available capacity is used in the most cost efficient way. Because there is limited storage space, the available storage space is checked before deciding to add a service part to a fieldstock location.

**Step 3**
When the solution found in step 2 is not feasible, i.e. the required target fill rates are not achieved, the final step is to iteratively increase the base stock levels until the performance restriction is met. For each combination of SKU \( i \in I \) and fieldstock location \( j \in J \), the base stock levels \( S_{i,j} \) are increased, starting with the base stock level \( S_{i,j} \) that provides the largest increase in fill rate per unit cost and unit volume. It is important to note that due to the storage restrictions, no feasible solution might be possible. In this case the solution offering the highest possible performance is chosen.

**4.6. Programming language**
Based on the decoupling and solving algorithms, a tool has been programmed in Microsoft VBA. The main reason for choosing this programming language is that all of the relevant reporting at Ricoh is in the form of Microsoft Excel sheets. This makes reporting at Ricoh highly compatible with any tool written in Microsoft VBA. Although there are other programming languages that are compatible with Microsoft Excel output, such as Delphi which was used by Kranenburg (2006), due to having more programming knowledge of Microsoft VBA and because the tool was programmed from scratch, Microsoft VBA is the programming language of choice.

**4.7. Conclusion**
In this chapter a methodology has been presented, designed to determine service part base stock levels for the fieldstock locations given storage capacity restrictions and aggregate fill rate performance targets. The methodology makes use of two algorithms, the first of which can determine the cost of a given base stock policy and the second of which can iteratively determine the policy with low as possible cost. One of the main input parameters of this method is the demand. As discussed in chapter 3, service part demand can be subject to fluctuations caused by seasonal effects. The fieldstock model is not designed to cope with these fluctuations and its impact is unknown. To cope with both short and long term demand fluctuations, the base stock levels should be updated over the course of time. To determine how often and at which moment this should be done, chapter 5 will discuss how the consequences of updating the base stock levels can be investigated and how seasonality can be taken into consideration.
5. Base stock level updating

Because service part demand is an important determinant of the base stock levels, the demand fluctuations described in chapter 3 can cause any calculated set of base stock levels to become outdated. To adapt the inventory levels more accurately to the demand fluctuations the base stock levels should be updated more frequently resulting in calculating the demand rates for the service parts over a smaller period. Although updating the base stock levels may lower inventory costs and costs due to second visits, handling costs may go up due to the removal of superfluous parts and the supply of additional parts. This requires an assessment of how the update frequency influences the total costs and performance levels achieved. Section 5.1 will start with a description of how updating occurs. Section 5.2 follows with a mathematical description of the costs related to updating. Section 5.3 describes several test configurations, designed to assess different update frequencies and forecasting methods with regard to the associated costs and performance levels.

5.1. Process of updating

When the base stock level for a service part is updated, the level either increases or decreases depending on how demand has developed. While increasing the base stock levels requires additional service parts to be ordered, which happens immediately after the new base stock levels go in effect to ensure the target fill rate performance, decreasing the base stock levels can happen in two ways. Either replenishment of inventory is ceased until the inventory level reaches below the new base stock level due to demand, or the service parts are immediately sent back to the central warehouse, depending on which of the two is the cheapest. Because the central warehouse is managed financially independent from the fieldstock locations it is possible to send service parts back to the central warehouse at a reduced rate of x% of the original value. The central warehouse then regains ownership of the service parts that get sent back. It is assumed the central warehouse does not experience any storage capacity restrictions when service parts are sent from the fieldstock locations back to the central warehouse.

5.2. Cost of updating

When considering the consequences of updating the base stock level for a service part the handling and regular replenishment costs are of importance. There are three types of costs associated with updating the base stock level for service part \( i \) at fieldstock \( j \), where \( M_{i,j} \) denotes the expected demand rate for service part \( i \) at fieldstock \( j \) after updating, \( S_{i,j}^{old} \) denotes the base
When the base stock level increases, handling and transportation costs are incurred for a regular shipment: \( \left[ S_{i,j}^{\text{new}} - S_{i,j}^{\text{old}} \right]^+ \cdot C^{\text{reg}} \).

When the base stock level decreases the minimum is incurred of:

- the loss of value when selling service parts back to the central warehouse (this is \((1-x)\%\) of the value of the service part) plus handling and transportation costs incurred for sending service parts back denoted by \( C^{\text{back}} \) per item plus the wage of the service engineer which is equal to one minute per part per update at the cost of the rate of a service engineer \( (C^{SE} \text{ per hour}) \): \( \left[ S_{i,j}^{\text{old}} - S_{i,j}^{\text{new}} \right]^+ \cdot \left( C^{\text{back}} + (1-x) \cdot P_i + \frac{1}{60} \cdot C^{SE} \right) \).

- the additional holding costs related to having additional inventory higher than the base stock level. These are equal to the time it takes for the inventory level to become equal to the new base stock level, multiplied by the average ‘additional inventory’ during that time and the holding cost per time unit: \( \left[ \frac{S_{i,j}^{\text{old}} - S_{i,j}^{\text{new}}}{2} \right]^+ \cdot C^{h}_{i,j} \).

Note that the decision to send the excess inventory for an SKU back (or not) is determined for each SKU \( i \in I \) separately and that in case the base stock level for an SKU decreases and the expected demand after updating is equal to zero, the excess items are always immediately sent back.

**Cost of one base stock level update for SKU i at fieldstock j**

\[
\begin{align*}
\text{Cost} &= \left[ S_{i,j}^{\text{new}} - S_{i,j}^{\text{old}} \right]^+ \cdot C^{\text{reg}} \\
&+ \min \left( \left[ S_{i,j}^{\text{old}} - S_{i,j}^{\text{new}} \right]^+ \cdot \left( C^{\text{back}} + (1-x) \cdot P_i + \frac{1}{60} \cdot C^{SE} \right) , \left[ \frac{S_{i,j}^{\text{old}} - S_{i,j}^{\text{new}}}{2} \right]^+ \cdot C^{h}_{i,j} \right)
\end{align*}
\]

(8)

5.3. **Comparing update frequencies**

To be able to test the effect of the update frequency with regard to cost and fill rate performance, different settings should be tested. The test configurations are compared as shown in figure 14. Using demand from review period \( t \), the base stock levels are calculated for
each SKU at every location within the lockerpoint region. These base stock levels are then used to calculate the costs and performance levels achieved when applying them during the following period, i.e. when choosing the base stock levels as the inventory levels during period $t+1$ and determining the performance when demand from period $t+1$ occurs. The mathematical model underlying the fieldstock model is used to calculate the cost and performance levels. This procedure is executed for all available review periods $t$, excluding the last one because that period does not have any demand data from period $t+1$ to test the base stock levels on. Next the costs related to updating the base stock levels are calculated. To allow for a fair comparison between different updating frequencies, each review period should end with a base stock level update. Eventually this leads to the total costs and performance for a given update frequency.

Figure 14. Method by which the performance of the update frequency is determined

5.4. Conclusion

This chapter described the process of updating and presented a mathematical description to calculate the associated costs. By applying this method in combination with the fieldstock model designed in chapter 4, the total long term cost and service level performance can be determined. The following chapter presents a case study in which this method is applied.
6. Ricoh case study

In this chapter the fieldstock model is applied in a case study at Ricoh Netherlands. The aim of this is to find out whether the fieldstock model can improve inventory management at Ricoh with regard to the total supply chain costs and fill rate performance and what the impact of the update frequency is. In section 6.1 the assumptions necessary to apply the tool at Ricoh are discussed. The required input parameters are discussed in section 6.2, followed by section 6.3 in which the results of applying the tool at Ricoh are presented and discussed.

6.1. Assumptions

To be able to apply the fieldstock model presented in chapter 4 the following assumptions should hold:

- Service part failure has the same effect on a machine for all parts
- Service part demand is Poisson distributed
- Infinite service part supply from the central warehouse
- One-for-one service part replenishment policy
- Replenishment lead times are independent
- Transportation times and costs are constant
- Holding costs are also charged over items in the replenishment pipeline

These assumptions are now discussed for the case study at Ricoh.

**Service part failure has the same effect on a machine for all items**

It is assumed that failure of a service part has the same effect on a machine for every service part. This means that regardless of how a service part might affect the functioning of a machine, the end result of that service part failing is the same for all parts in the sense that the failure prohibits the machine from being used properly, causing demand for a service part at one of the fieldstock locations with similar urgency. Therefore, service part failure has the same influence on the service part distribution network, regardless of the importance of the service part.

**Demand is Poisson distributed**

Demand is assumed to be Poisson distributed. To test this assumption, for a set of SKU, a goodness-of-fit test is executed based on the Chi-square distribution (Montgomery & Runger, 2007). This procedure is described in Appendix C and shows that for 78% of the tested service parts the hypothesis of having Poisson distributed demand cannot be rejected. Further investigation of the remaining 22% shows that clustering sometimes occurs when service engineers register their service part usage. This means service engineers register usage for a several parts at the same moment causing the demand distribution to be altered. According to
the department of Hardware & Inbox Solutions this tends to occur because it is sometimes more convenient for service engineers or because they forget to do it. This complicates determining whether demand for those service parts is Poisson distributed, causing the percentage of service parts that experience Poisson distributed demand to be underestimated. Based on this it is assumed all service parts experience Poisson distributed demand and all considered service parts are therefore included in the case study. Furthermore, not including these parts would complicate assessing whether storage capacity restrictions are met by the fieldstock model.

Infinite service part supply from the central warehouse
Any demand requested from the central warehouse by the fieldstock locations can be shipped immediately, i.e. the fill rate achieved at the ESPC is assumed to be 100%. However in real-life the fill rate achieved at the ESPC is equal to 97%. Although this is slightly less, this assumption seems to be a fair one.

One-for-one replenishment policy
A one-for-one replenishment policy is assumed. This means that as soon as a service part is used, a new item is ordered. This is an (S, S-1) continuous review base stock policy. At Ricoh review occurs daily, meaning that when demand during a certain day is more than 1 the inventory level will drop below S-1. However, for the OP engineers in the South East region, only 2% of all SKUs that experienced demand during the 1st of July 2013 until the 31st of December 2013 experienced a demand of more than 1 item per day. The average daily demand for an SKU was equal to 0,1 during that period. There is no reason to think this is different for other periods. Therefore, the assumption of one-for-one replenishment is acceptable for most of these items.

Replenishment lead times are independent
Both for different SKUs and per SKU, the replenishment lead times are assumed to be independent. Although combined delivery due to order consolidation at the central warehouse occurs for service engineers, the lead time depends mostly on the replenishment moments. These are determined by the service engineers themselves and almost all engineers get replenished on a daily basis. Therefore, the replenishment lead time is independent of any other SKUs that need to be delivered to a fieldstock.

Transportation times and costs are constant
It is assumed that transportation from the central warehouse to the fieldstock locations occurs with constant transportation times and costs. Kranenburg (2006) justifies this assumption by reasoning that the distance between the central warehouse and the set of local warehouses is relatively high compared to the distances between fieldstock locations. In that case the
replenishment distances (and therefore time and cost) to each of these fieldstock locations are relatively similar, in comparison to the much smaller distances between the fieldstock locations. For the case of Ricoh this does not hold; the ESPC is located in the Netherlands and distances to the fieldstock locations can therefore vary considerably. However, because replenishment occurs daily and at a set time, the lead time is relatively constant for every service engineer, which makes the assumption a reasonable one. Transportation times and costs between carstocks and customers are equal to zero. This is due to the fact that when customer demand occurs at a carstock, the carstock is already physically present at the customer.

*Holding costs are charged over items in the replenishment pipeline*

Kranenburg (2006) assumes that as soon as items are shipped from the central warehouse, holding cost are incurred over those items. Because ownership of items that leave the ESPC is immediately transferred to Ricoh Netherlands this assumption is justified.

### 6.2. Input Parameters

There are 6 types of input parameters required by the fieldstock model:

- number of carstocks in a lockerstock region
- cost, time and performance parameters
- service part prices and volume characteristics
- capacity restrictions of the fieldstock locations
- service part demand rates

#### 6.2.1. Lockerstock region

Because service engineers are assumed to only visit one lockerpoint and the South East region has four lockerpoints, one lockerpoint is selected for the analysis. The lockerpoint that contained the largest financial inventory investment is used in this research (codename RNLL800). The service engineers that make use of this lockerpoint are chosen based on the proximity of the lockerpoint to their homes. This means that every service engineer always visits the lockerpoint located closest to their home. Based on this assumption, in total 16 currently active engineers are linked to this lockerpoint.

#### 6.2.2. Cost, time and target performance parameters

The fieldstock model requires several input parameters and based on information gathered at Ricoh, the ESPC and the logistics company that transports service part replenishments from the ESPC to the fieldstock locations, these were determined for the case study. Next it is discussed how these are calculated.
The cost of replenishing a single item ($C^{reg}$) consists of handling costs at the ESPC plus the cost of transportation. Handling costs per service part for a normal replenishment are standard rates acquired from the ESPC and the transportation costs are calculated by dividing the total yearly transportation costs for replenishment by the average number of items shipped per year.

By applying the standard hourly rate Ricoh applies for a service engineer ($C^{SE}$) and adding the cost of a replenishment ($C^{reg}$), the cost parameter for a visit to the lockerpoint can be calculated. The average distance between a service engineer his home and the lockerpoint is determined to be 25 kilometres. By assuming an average travel speed of 60 km/h this takes 25 minutes. Adding the handling time necessary on site, the total time a lockerpoint visit takes is assumed to be 1 hour. Analogous to this, the cost parameter for a second visit is calculated by using the average time a second visit requires, which is determined using service activity data registered by Ricoh and is found to be 2.13 hours. By applying the aforementioned hourly rate ($C^{SE}$) for a service engineer and the addition of transportation costs and handling costs for an emergency shipment the cost parameter can be determined.

The transportation company contracted by Ricoh charges a fixed amount for each delivery or pickup, i.e. deliveries from the ESPC to a fieldstock and vice versa. In case both are required during the same trip, an additional 10% is charged on top of the fixed amount. Tests showed that when the base stock levels are updated for all fieldstock locations both deliveries and pick-ups always occur. Therefore the main transportation charge is already incorporated in the cost of replenishment ($C^{reg}$). The additional 10% for the pickup would have to be paid 17 times per update (for each fieldstock), resulting in a very small total cost increase causing a cost of sending items back to the ESPC per item ($C^{back}$) to be negligible compared. Therefore $C^{back}$ is set to zero. It is assumed the transportation company is not going to change its tariff as the service it provides to Ricoh only represents a small portion of its total number of deliveries and therefore is of little influence to their business.

Because the cars used by the service engineers are necessary regardless of whether any service parts are stored there, no storage cost (rent) is charged for items stored in a car. Because the lockerpoints are rented specifically for service part storage, a storage cost per unit volume is charged for storage at a lockerpoint ($C^S_{i,j}$). This is calculated by dividing the yearly cost of lockerpoint rental by the average volume of service parts stored at the lockerpoint.

The cost of obsolescence per euro of inventory is based on the reservations Ricoh made on its balance for this type of cost. This parameter is calculated as the ratio between the reservation for a period and the total value of the average inventory during that period. The interest of a Dutch government bond is used as the opportunity cost per euro of inventory because this is the minimum possible return on an investment with minimum risk.
In case an item is ordered during workday t, replenishment takes place at the start of workday t+2. The replenishment time is therefore 1 workday in case ordering takes place at the end of day t and 2 workdays in case the order is placed at the start of day t, making the average replenishment time equal to 1.5 workdays. The target fill rate performance is set to 95% for all engineers.

6.2.3. Service part prices and volume characteristics

Because the ESPC repairs some of the broken service parts that are returned, prices can vary based on whether the service part is refurbished or new. Therefore the average cost price Ricoh Netherlands pays for a service part when ordering it from the ESPC is used to represent the cost price of a service part.

SKU's with a cost price of less than €12,50 are not considered in this case study. This is done because enforcing higher level inventory control for these relatively cheap items is of little importance to the cost effectiveness as long as the stock level does not drop below the point of causing second visits (i.e. causing expensive emergency deliveries). Because inventory costs for these items are low a large safety stock can make sure stock outs do not occur. When analysing the 50 engineers in the South East region that used service parts worth over €12.50 and worth under €12,50, 80% had a higher stockout rate for the former group compared to the latter group. The decision to exclude service parts worth less than €12,50 is justified because almost all of these parts concern small parts that are stored in a special suitcase. Therefore, for inventory quantities that aren't too exorbitant, the amount of space these SKU's occupy is determined by the size of the suitcase and not by the number of items in stock. Their inventory levels therefore do not influence the storage capacity. Also, due to their low prices they have relatively little impact on the total costs. Service parts with a cost price less than €12,50 represent only 5% of the value of total demand July 2013 until December 2013. Therefore, excluding these items from the analysis does not impact the financial relevance of the analysis, given they do not cause second visits. Furthermore, seasonality is mainly present in PCUs charge rollers drums, which are all service parts with a cost price higher than €12,50. It is important to note that although tools, consumables and the SKU's under €12,50 will not be considered during the analysis, the space these items take up in the carstocks is considered because the fieldstock model considers storage capacity restrictions.

Because the available case study data only contains information on the weight of the service parts, their sizes are determined using those weights. For this to be possible, weight should be an appropriate indication of the size of an SKU. The relation between weight (x) and volume (y) is determined as follows. The least squares fitting technique (Montgomery & Runger, 2007) is used on a sample of 46 service parts worth over €12,50, that have been measured with regard
to their volume, to describe a line \((y)\) that best predicts the set of known data points. This is
done by determining the constant \(b\) and regression coefficient \(m\) for \(y\), so that the sum of the
squared distances between the \(x\) values and the line are minimized: \(y = b + mx\). Because a
weight of zero should match a volume of zero, the constant \(b\) was set equal to zero. By applying
the least squares fitting technique the following model is found: \(y = 10.4x\). This model has an \(R^2\)
of 0.804 which means it can account for more than 80% of the variance in \(x\). The sample
contains service parts in the range of 30 grams up to 2.27 kilo, where the demand data contains
service parts in the range of 2 grams up to 30 kilo. In total, about 10% of the part demand
during 2011 until 2013 was found to concern parts over 3 kilo. Furthermore, the model is found
to predict the size of larger parts as well as those of smaller parts.

6.2.4. Fieldstock capacity restrictions

Of the 16 engineers, 11 engineers drive a station wagon and 5 drive a van, the main difference
being that the latter type is bigger and does not have a rear seat. Because all cars are acquired
based on a lease contract in which the engineer pays a certain amount which allows him to use
the car for personal affairs, engineers prefer to not store any items on the rear seat. Therefore,
the storage space of a station wagon is based on the trunk space of the vehicle. The capacity
restriction of each carstock was determined by looking up volume specifications presented on
the official websites of the respective cars. Because all service engineers have to carry tools,
consumables and the service parts under €12,50 with them, the available carstock volumes
need to be adjusted by 247 litres. The resulting storage capacity restrictions are depicted in
table 1 and engineers 5 until 9 are the ones who drive a van. The lockerpoints Ricoh use have
about 12000 litres of storage capacity.

<table>
<thead>
<tr>
<th>Fieldstock location (j)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_j^{\text{max}})</td>
<td>253</td>
<td>253</td>
<td>253</td>
<td>277</td>
<td>3553</td>
<td>3553</td>
<td>1753</td>
<td>3553</td>
<td>1753</td>
<td>253</td>
<td>277</td>
<td>253</td>
<td>277</td>
<td>277</td>
<td>253</td>
<td>253</td>
<td>12000</td>
</tr>
</tbody>
</table>

*Table 1. Maximum storage capacities in litres for all fieldstock locations*

6.2.5. Demand rate calculation

The fieldstock model requires demand rates denoted by \(M_{i,j}\) as input. These are determined for
each SKU \(i\) and fieldstock location \(j\) and represent the expected demand during the review
period. Kranenburg (2006) uses the average yearly demand for SKU \(i\) experienced by fieldstock
c. This \textit{SE-based demand rate} is calculated by using the demand an individual engineer
experienced:

\[
M^\text{SE}_{i,c} = \text{Total demand SE } c, \text{SKU } i
\]
This research suggests an alternative to the SE-based demand rate. A service engineer can experience demand for any of the service parts belonging to the product families he is trained on. As engineers might experience low demand for a service part due to chance, determining average (future) demand rates for each service engineer based on his skills can provide more robust estimates of the demand rates compared to using SE-based demand rates. This skill-based demand rate is calculated by dividing the total demand for a service part within a lockerpoint region during the review period by the total number of engineers that service the product family to which the service part belongs. If service engineer $c$ is trained on skill $s$ and item $i$ ‘belongs’ to skill $s$, the demand rate for item $i$ and service engineer $c$ is calculated as follows:

$$M_{l,c}^{skill} = \frac{\text{Total demand for SKU } i \text{ belonging to skill } s}{\text{Total } \# \text{ of SEs that have skill } s} \quad (9)$$

To illustrate the difference between the SE-based and the skill-based demand rates an example is shown in table 2 for the skill related to product family Apollon. Only three engineers are assumed to be trained on product family Apollon in this example.

<table>
<thead>
<tr>
<th>Service engineers $c$</th>
<th>Skill $s$</th>
<th>$M_{l,c}^{SE}$</th>
<th>$M_{l,c}^{skill}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>APOLLON</td>
<td>0</td>
<td>$(0+8+4)/3 = 4$</td>
</tr>
<tr>
<td>B</td>
<td>APOLLON</td>
<td>8</td>
<td>$(0+8+4)/3 = 4$</td>
</tr>
<tr>
<td>C</td>
<td>APOLLON</td>
<td>4</td>
<td>$(0+8+4)/3 = 4$</td>
</tr>
</tbody>
</table>

Table 2. Calculation example for SE-based and skill-based demand rates

The numbers show that the skill-based method redistributes total demand for an SKU evenly over all engineers that might require that item in the future, thus smoothing out any extremely high or low demand rates. To test which method actually provides better results with regard to the supply chain costs and fill rate performance, both methods were tested by determining base stock levels using demand from 2011 and 2012 and testing these base stock levels on demand from 2012 and 2013, respectively. Table 3 shows the total supply chain costs and the average first visit fill rate and 'BS levels 2011' refers to the base stock levels calculated using demand from 2011. The cost figures are normalized by setting the costs for the SE-based data for 2011-2012 to 100 and determining the other cost figures relative to this. The table shows that the

<table>
<thead>
<tr>
<th>SE-based</th>
<th>Skill-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS levels 2011</td>
<td>BS levels 2012</td>
</tr>
<tr>
<td>Demand 2012</td>
<td>Demand 2013</td>
</tr>
<tr>
<td>Total supply chain cost</td>
<td>100</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>90,6%</td>
</tr>
<tr>
<td>Total investment</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3. Comparing demand rate calculation methods
skill-set based results give better cost and fill rate performance at the cost of a higher inventory investment. Therefore, the skill-based demand rate comes out best and therefore this method is used in the case study. Thus, \( M_{tj} = M_{t,c}^{skill} \) for all \( c \in J/\{l\} \) and \( M_{tj} \) remains equal to zero.

**Forecasting method**

Two demand forecasting methods are applied in this research. The first one is the simple moving average (SMA) which calculates average demand rates using a moving forecast horizon (the review periods mentioned in chapter 5). The second method is the multiplicative Holt-Winters method (HW) which considers seasonality. In their paper Dekker et al. (2004) found that for seasonal demand, forecasting error was reduced by 37% on average, compared to the standard Holt-Winters method when applying product-aggregation. Another paper that focused on determining the improvements of forecasting seasonal items on the group level instead of on the item level is the paper by Ouwehand (2006). This paper also found that aggregate forecasting can deliver more accurate item level forecasts than the standard Holt-Winters method. Both papers consider the Holt-Winters exponential smoothing procedure as the underlying forecasting method. Dekker et al. (2004) chose this method for two reasons. Firstly, the method is easy to understand and secondly, it works fast which is desirable when a lot of items require forecasting. Practical usability is of importance in this research and both the speed and comprehensibility of the procedure contribute to this. The reason for using the multiplicative method instead of the additive method is because the former one performs better when the seasonal variations proportionally change over time. According to de Leeuw et al. (1998) trends should only be considered when there is a clear trend in the data. Because the trends for the seasonal service part categories discussed in chapter 3 were found to be caused by changing operational guidelines, no trend components are considered. Therefore, forecasting in this research is done according to the multiplicative Holt-Winters method on the product-aggregated level.

Applying the multiplicative Holt-Winters method as described by Dekker et al. (2004) on the entire dataset requires a high computation time when considering skill-based demand rates, as there are 4 service part categories, more than 1000 SKUs that experienced demand from 2011 until 2013, 16 engineers and 45 skills resulting in 2.8 million computations per review period. This causes an incredibly high computation time estimated to be more than 11 hours. Therefore, to account for the seasonality in demand a more simple technique is applied. For each of the 4 service part categories demand is forecasted on aggregate according to the Holt-Winters method. The ratio between the actual aggregate demand in period \( t \) and the forecasted aggregate demand for period \( t+1 \) is then calculated and used to determine forecasts at the item level.
\[ \text{ratio}_t^r = \frac{\text{Aggregate demand forecast category } r, \text{ for period } t + 1}{\text{Actual aggregate demand category } r, \text{ for period } t} \]  

(10)

where \( \text{ratio}_t^r \) is the ratio determined at the end of period \( t \) for category \( r \).

Service part demand during period \( t \) is multiplied by the ratio of the respective service part category to determine the item level forecast for period \( t+1 \):

\[ \text{Demand forecast } SKU \ i, \text{ for period } t + 1 = \text{ratio}_t^r * \text{Actual demand } SKU \ i, \text{ for period } t \]  

(11)

This technique will enable showing whether considering seasonality can contribute to better performance without the procedure becoming too time consuming. The complete forecasting procedure can be found in Appendix D.

6.2.6. Base stock level updating

Review period

Review periods of a year, half a year and a quarter of a year are considered. The reason for this is that shorter periods are not expected to provide better forecasting results due to the high variation on a monthly level. Longer review periods than a year will cause too much emphasis to be placed on service part demand that occurred a long time ago and recent demand developments to be undervalued. As discussed in chapter 3, review periods are matched to the seasons, resulting in four quarterly periods starting at the 21st of March, the 21st of June, the 21st of September and the 21st of December. The half year periods start at the 21st of May and the 21st of November. Because demand data is available for three years, this results in 5 review periods of half a year and 11 periods of a quarter year.

Test configurations

The impact of the updating frequency on the performance of the fieldstock model and the application of the forecasting methods is tested for four test configurations. Test configuration 1, 2 and 3 apply SMA for review periods of a year, half a year and a quarter, respectively. Configuration 4 applies HW for the half year and quarterly review periods using indices determined for each of the service part categories on aggregate. Based on the findings discussed in chapter 3, HW is not considered for a review period of a quarter because the seasonal effect

<table>
<thead>
<tr>
<th>Test configurations</th>
<th>Forecasting method</th>
<th>Review period</th>
<th>Update frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SMA</td>
<td>Year</td>
<td>Annually</td>
</tr>
<tr>
<td>2</td>
<td>SMA</td>
<td>Half year</td>
<td>Semi-annually</td>
</tr>
<tr>
<td>3</td>
<td>SMA</td>
<td>Quarter</td>
<td>Quarterly</td>
</tr>
<tr>
<td>4</td>
<td>HW</td>
<td>Half year</td>
<td>Semi-annually</td>
</tr>
</tbody>
</table>

*Table 4. Test configurations*
was found to shift from year to year. HW is not considered for a review period of a year because this will even out the seasonal effect. The test configurations are shown in Table 4.

6.3. Results

In this section the results of applying the fieldstock model to actual demand data are presented. Demand data from 2011 until 2013 has been collected for the 16 service engineers which are part of the region in which lockerpoint RNLL800 is located. The aim of this section is threefold. Firstly, the performance of the fieldstock model and its sensitivity to different values for some of the input parameters is discussed. Secondly, the results of applying the fieldstock model at Ricoh are presented and compared to the real-life situation during 2013. Thirdly, the test configurations described in section 6.2 are used to show the impact of the update frequency and the forecasting method on the performance of the fieldstock model.

6.3.1. Fieldstock model performance

In this section the base stock levels determined using demand data from 2011 are tested on demand data from 2011 and the same is done for 2012 and 2013. Table 5 shows the achieved cost and fill rate performance for service part demand from 2011, 2012 and 2013. The carstock fill rate represents the percentage of demand fulfilled directly from carstock. Given the input parameters for Ricoh, the cost optimal solution already achieves a 99.6% average fill rate performance for all years, i.e. step 3 of the solving algorithm (discussed in chapter 4) was not necessary. The reason for this is the relatively high costs incurred for a second visit. These are considerably higher than the costs related to service part storage, which causes the model to avoid second visits by maximizing inventory levels and accepting those storage costs. The high base stock levels required to achieve a first visit fill rate of 99.6% result in 13 out of the 16 carstocks reaching their maximum storage capacity for 2013 (i.e. the fieldstock model tried to add more items to the base stock level than possible due to the capacity restriction). The other three engineers are the ones that own a van instead of a station wagon, showing that the storage capacity is a serious restriction. This causes the carstock fill rate to stay around 70% for all three years. To overcome the storage capacity restriction for those engineers and achieve the overall cost optimal solution, the lockerstock location is used. The inventory investment for the carstocks and the lockerpoint is presented as a percentage of the total inventory investment and the data show that the lockerpoint consistently holds about 25% of the total inventory investment, allowing about 30% of demand to be fulfilled from the lockerpoint, resulting in the high first visit fill rate. To investigate the impact of the capacity restrictions ($V_{j_{max}}$) the situation where the storage capacity is unrestricted is analysed next. Also, a sensitivity analysis is
performed on the cost parameter related to second visits ($C^{em}$). The parameters are analysed using demand data from 2013 forecasted using SMA, because this is the most recent data.

<table>
<thead>
<tr>
<th></th>
<th>BS levels 2011 Demand 2011</th>
<th>BS levels 2012 Demand 2012</th>
<th>BS levels 2013 Demand 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total amount of items in inventory</td>
<td>2314</td>
<td>2229</td>
<td>2551</td>
</tr>
<tr>
<td>Total inventory investment</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Lockerstock investment</td>
<td>27</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Carstock investment</td>
<td>73</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>SEs with insufficient storage capacity</td>
<td>10</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Average carstock fill rate</td>
<td>71,4%</td>
<td>73,1%</td>
<td>70,7%</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>99,6%</td>
<td>99,7%</td>
<td>99,6%</td>
</tr>
<tr>
<td>Average second visit rate</td>
<td>0,4%</td>
<td>0,3%</td>
<td>0,4%</td>
</tr>
</tbody>
</table>


**Storage capacity restriction**

To determine the required storage capacity and the related cost and fill rate performance, the situation with the original values of $V_j^{max}$ as determined for Ricoh, is compared to the situation where no storage capacity restrictions are present. The financial data is normalized by using the cost performance for the original values of $V_j^{max}$ as a reference and determining the other cost figures relative to these values. The information in table 6 shows that removing the storage capacity restriction causes the total inventory investment to increase and allow for a 29% decrease in supply chain costs compared to those achieved with the original storage capacity of $V_j^{max}$. This cost optimal solution is found for an additional inventory investment of 70%. In this case, the number of service engineers that were found to have insufficient storage capacity logically is zero, where it is equal to 13 for the original values for $V_j^{max}$. When the storage capacity is increased, the carstock investment increases while the lockerstock investment decreases. This is due to the fact that demand fulfilment from the lockerpoint is more expensive compared to fulfilment from the carstock and shows that the lockerstock is used to compensate when there is insufficient storage space in the cars. The carstock fill rate is therefore also found

<table>
<thead>
<tr>
<th></th>
<th>$V_j^{max}$</th>
<th>$V_j^{max}=\infty$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total supply chain costs</td>
<td>100</td>
<td>71</td>
</tr>
<tr>
<td>Total inventory investment</td>
<td>100</td>
<td>170</td>
</tr>
<tr>
<td>Lockerstock investment</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>Carstock investment</td>
<td>100</td>
<td>198</td>
</tr>
<tr>
<td>SEs with insufficient storage capacity</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Average carstock fill rate</td>
<td>70,7%</td>
<td>83,0%</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>99,6%</td>
<td>99,9%</td>
</tr>
<tr>
<td>Average second visit rate</td>
<td>0,4%</td>
<td>0,1%</td>
</tr>
</tbody>
</table>

*Table 6. Fieldstock model performance for 2013 with unrestricted storage capacity.*
to increase by almost 13 percentage points when there is ample carstock capacity. The fact that almost 17% of demand is fulfilled by visiting a lockerpoint, even though there is ample carstock capacity, shows that stock pooling can improve cost performance of the distribution network. For some of the engineers that use a station wagon the total storage capacity required when optimizing this capacity can be as much as 7 or 8 times larger than the original storage capacity. Even considering the extra storage space that comes from utilizing the rear seat does not provide enough capacity for those engineers. The largest service vehicle currently in operation at Ricoh will allow all service engineers within the considered lockerpoint region, with the exception of one, to store the recommended service part base stock levels. Although using these vans would be best with regard to inventory management, the cost of using them is higher than those for station wagons. Per month this amounts to about €x per vehicle. For the lockerpoint region considered in this case study, this would amount to an additional cost of 16% of the total supply chain costs for the original values of $V_i^{\text{max}}$. This causes the total supply chain costs for the situation with unlimited storage restrictions to still result in a 13% (29% minus 16%) decrease in supply chain costs compared to the situation with storage capacity constraints and shows that the investment in larger vehicles is justified from the viewpoint of inventory management.

**Sensitivity analysis second visit cost parameter**

Table 7 shows the impact of adjusting the cost parameter $C_{em}$. The financial data is normalized by using the cost performance for the original values of $C_{em}$ as a reference. To interpret the results presented in the table, it is important to realize that $C_{lock} \approx 0.5 \times C_{em}$. Because the cost of a second visit should always be higher than the cost of visiting a lockerpoint to ensure that the demand fulfilment order discussed in chapter 3 and 4 is applicable, the cost of a second visit is never chosen lower than the cost of visiting a lockerpoint. If it would be, storing inventory at a lockerpoint would never be beneficial with regard to the total supply chain costs (as allowing second visits would then be cheaper) and only of interest to achieve the target fill rate performance. The table shows that if $C_{em}$ is reduced, the total inventory investment decreases due to the fact that more second visits are accepted by the fieldstock model. Because fulfilment from a lockerpoint is a lot more expensive than fulfilment from a carstock, the decrease in inventory investment is the largest for the lockerpoint. Because both the carstock fill rate and the second visit rate increase, the number of visits to the lockerpoint decreases causing a decrease of the supply chain costs. Lowering the cost of a second visit causes the second visit rate to increase to such an extent that the total costs related second visits increase. This is however not that enough to prevent the supply chain costs from decreasing.
Table 7. Fieldstock model sensitivity analysis of \( C_{\text{em}} \) for 2013.

<table>
<thead>
<tr>
<th></th>
<th>0.6( C_{\text{em}} )</th>
<th>0.8( C_{\text{em}} )</th>
<th>( C_{\text{em}} )</th>
<th>1.2( C_{\text{em}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total supply chain costs</td>
<td>76</td>
<td>88</td>
<td>100</td>
<td>109</td>
</tr>
<tr>
<td>Total inventory investment</td>
<td>77</td>
<td>93</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>Lockerstock investment</td>
<td>49</td>
<td>86</td>
<td>100</td>
<td>106</td>
</tr>
<tr>
<td>Carstock investment</td>
<td>86</td>
<td>96</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>SEs with insufficient storage capacity</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Average carstock fill rate</td>
<td>78.9%</td>
<td>75.1%</td>
<td>70.7%</td>
<td>67.3%</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>97.3%</td>
<td>99.2%</td>
<td>99.6%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Average second visit rate</td>
<td>2.7%</td>
<td>0.8%</td>
<td>0.4%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

6.3.2. Fieldstock model and real-life performance

To test how the fieldstock model performs compared to real-life, in this section the fieldstock model is applied by determining base stock levels using demand from 2012 (and SMA as forecasting method) and testing these base stock levels on demand from 2013. Due to the limited availability of information on inventory levels in the past, the real-life inventory levels are determined based on data collected at the 1st of August 2013. To determine the performance of these inventory levels the fieldstock model is used to test them as base stock levels on demand during 2013. Because the real-life inventory levels fluctuate a lot over time and service part registration has been incorrect in the past, the average first visit fill rate calculated by the fieldstock model was found to be much lower than the overall achieved first visit fill rate reported by Ricoh (17.5% instead of 77.9%) when. Therefore the fill rate performance of the fieldstock model is compared to the reported fill rate performance. The inventory levels at the 1st of August were however used to calculate the real-life inventory investments. Table 8 presents the cost and fill rate performance and the inventory investment information for the fieldstock model and real-life. The total real-life supply chain costs have been estimated and the fieldstock model reduces these by 13%, while improving the first visit fill rate performance from 77.9% to 92.4%. The lockerpoint inventory as determined by the fieldstock model is found to have a value almost 7 times greater than the real-life lockerpoint inventory investment and the carstock inventory investment is determined to be 67% higher than the real-life inventory, resulting in an increase of total inventory by 108%. Based on the higher first visit fill rate performance and the fact that the cost of a second visit is dominant in this model, this increase is logical. The shift towards allocating more inventory to the lockerpoint suggests that the model makes use of stock pooling. In chapter 3 it was discussed that stock pooling would be most beneficial for large and expensive parts. The findings of the fieldstock model show that the average part in a lockerpoint is almost 40% larger and 46% more expensive than the average part in a carstock, thus confirming this. The high total inventory investment results in a high fill rate performance. So although performance is improved by the fieldstock model, this requires
an increase in the amount of inventory kept in storage. This confirms the complaints of insufficient storage capacity in the engineers their cars.

<table>
<thead>
<tr>
<th></th>
<th>BS levels 2012 Demand 2013</th>
<th>Actual inventory levels August 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total supply chain costs</td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>Total inventory investment</td>
<td>208</td>
<td>100</td>
</tr>
<tr>
<td>Lockerstock investment</td>
<td>691</td>
<td>100</td>
</tr>
<tr>
<td>Carstock investment</td>
<td>167</td>
<td>100</td>
</tr>
<tr>
<td>Average carstock fill rate</td>
<td>66,0%</td>
<td>n.a.</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>92,4%</td>
<td>77,89%</td>
</tr>
<tr>
<td>Average second visit rate</td>
<td>7,6%</td>
<td>22,11%</td>
</tr>
<tr>
<td>Average machine downtime (in working hours)</td>
<td>7,51</td>
<td>10,51</td>
</tr>
</tbody>
</table>

Table 8 Fieldstock model performance compared to real-life performance

Although the total time until repair (or downtime) is not implicitly considered in the fieldstock model, the model does influence this measure due to the fact that the model influences the number of lockerpoint visits and the number of second visits. Based on data of service, travel and response times for service requests performed during September 2013 until March 2014, an indication of the decrease in average downtime of machines is determined. The real-life downtime is determined straightforward by using the average total time until repair found in the dataset. The downtime achieved by the fieldstock model is calculated by adding up the average values for the response time, the service time and the time between a first visit and a return visit determined using the information available from the service request dataset. For the travel time required to visit a lockerpoint and the total time it takes to perform a second visit (including travelling time) the same values as those discussed in section 6.2 are used. By applying the fill rate percentages given by the fieldstock model, this allows estimating the average downtime of a machine. Table 8 shows that the fieldstock model helps to reduce the average machine downtime by almost 30%. The reason for this is that the fieldstock model tries to reduce the number of second visits and the number of lockerpoints because these are relatively expensive. Because these two demand fulfilment options are also time consuming, the fieldstock model also decreases the average machine downtime.

As mentioned in chapter 1.3, Ricoh Europe is interested in lowering its total inventory investment. The analysis presented above shows that from a financial viewpoint this is not desirable. Based on interviews with the head of the department of Hardware & Inbox Solutions the reason Ricoh Europe is so keen on lowering inventory is because they charge higher holding costs for keeping inventory, specifically those relating to obsolescence. Based on financial information at Ricoh, the risk of obsolescence is represented by charging 4% obsolescence cost for the total value of service part inventory, whereas in the past as much as 20% obsolescence
cost has been proposed by the ESPC. The results of changing the parameter related to obsolescence costs \( f \) are shown in table 9. Although the inventory investment is lowered by almost 25% when using 20% obsolescence cost, the storage capacity is still insufficient for 11 out of 16 engineers, showing that increasing the obsolescence cost fivefold does not change the finding that storage capacity restrictions limit the cost performance.

<table>
<thead>
<tr>
<th></th>
<th>( f = 0.04 )</th>
<th>( f = 0.10 )</th>
<th>( f = 0.20 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total supply chain costs</td>
<td>100</td>
<td>105</td>
<td>112</td>
</tr>
<tr>
<td>Total inventory investment</td>
<td>100</td>
<td>88</td>
<td>76</td>
</tr>
<tr>
<td>Lockerstock investment</td>
<td>100</td>
<td>94</td>
<td>81</td>
</tr>
<tr>
<td>Carstock investment</td>
<td>100</td>
<td>86</td>
<td>74</td>
</tr>
<tr>
<td>SEs with insufficient storage capacity</td>
<td>13</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Average carstock fill rate</td>
<td>70.7%</td>
<td>70.3%</td>
<td>69.9%</td>
</tr>
<tr>
<td>Average first visit fill rate</td>
<td>99.6%</td>
<td>99.4%</td>
<td>99.1%</td>
</tr>
<tr>
<td>Average second visit rate</td>
<td>0.4%</td>
<td>0.6%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

Table 9. Fieldstock model sensitivity analysis of the optimal cost performance the obsolescence costs \( f \) for 2013

Base stock level updating

Following the method described in section 5.3, base stock level updating is discussed next. Figure 15 shows the relative cost and fill rate performance for each of the test configurations. The graph shows that increasing the updating frequency from once per year to once every 3...
months causes the supply chain costs to increase by almost 50%, while at the same time causing the average first visit fill rate performance to decrease by more than 2 percentage points. The overall cost increase can be attributed to both the increase of the number of second visits due to the lower performance and the increased number of updating moments. The performance decrease for shorter review periods can be explained by the fact that most service parts experience very low and intermittent demand, causing short review periods to ‘miss’ demand information about certain service parts, which a longer review period would include in the demand forecast. Choosing a shorter review period does result in lowering the storage costs. Because storage costs represent a very small portion of the total supply chain costs this has a negligible effect on the total supply chain costs. Although a seasonality effect has been identified in chapter 3, no improvements are achieved when forecasting demand using the Holt-Winters forecasting method with seasonality. This is due to the low demand per SKU-fieldstock combination, which causes the absolute difference between the SMA and the HW forecasted demand to not be large enough per SKU-fieldstock combination to cause any change in the calculated base stock levels.

### 6.4. Conclusions

This chapter presents the results of applying the tool designed in this research for a case study at Ricoh Netherlands, for the situation of a single lockerpoint region consisting of 16 engineers and one lockerpoint. Several conclusions with regard to application of the tool can be made based on the presented results:

- It is found that given the cost structure at Ricoh, the cost optimal solution is reached at a first visit fill rate performance of 99.6%. Due to the high costs concerned with a second visit, the target fill rate performance of 95% was reached for all instances.
- Compared to the real-life performance during 2013, the model was able to achieve an improvement of the first visit fill rate performance from 77.9% to 92.4% and a reduction of supply chain costs by 13%, by doubling the inventory investment. The average machine downtime decreased by almost 30%.
- Storage capacity was found to be a limiting factor for 13 of the 16 engineers when applying the fieldstock model during 2013. The remaining three engineers drive larger vehicles with significantly more trunk space. When offering all engineers the largest available service vehicle only one service engineer has insufficient storage capacity, reducing the resulting supply chain costs (including the additional costs of using these larger service vehicles) by 13%.
Results show that the lockerpoints are used to store the more expensive and voluminous service parts. This confirms the idea that stock pooling can be applied to reduce inventory costs and therefore have a lowering effect on total supply chain costs.

The fieldstock model was tested by considering the consequences of using the model to update the inventory base stock levels at different frequencies over a period of 3 years. Three different review periods (3, 6 and 12 months) were considered and the findings show that although the storage costs are slightly reduced, transportation costs, updating costs and the costs due to second visits increase when increasing the frequency with which updating is done. Updating the base stock levels once a year was found to be best both with regard to the supply chain costs and the fill rate performance. The fact that more second visits occur for shorter review periods shows that doing so degrades forecasting accuracy. The reason for this is that most service parts experience very low and intermittent demand, causing short review periods to exclude certain service parts, which a longer review period would consider.

Two different forecasting methods were considered in this research; the simple moving average and the multiplicative Holt-Winters method. The latter one was used to consider seasonality and it was found not to contribute to improved inventory management. Both the costs and the fill rate performance were found to be similar to those achieved by the simple moving average method. This was found to be due to the low demand per SKU-fieldstock combination, which causes the seasonality effect to result in very small absolute differences between the SMA and the HW forecasted demand rates. Therefore, the demand rates of both forecasting methods are too similar to cause any significant differences for the calculated base stock levels. Given this finding and the fact that the seasonality effect was very inconsistent for the considered 3 year period, application of any forecasting method which takes seasonality into consideration is unlikely to provide improvements over SMA.
7. Implementation plan

To successfully implement the tool at Ricoh several obstacles need to be overcome. This includes where responsibility for the tool should lie and how support and acceptance for its application can be achieved within the organization. These issues are discussed in section 7.1 and 7.2. Finally, the limitations of the tool are discussed in section 7.3.

7.1. Responsibility tool

This research shows that by applying the tool at Ricoh, inventory management can be improved. For these improvements to be achieved by Ricoh, the tool has to be implemented and the first step to do this is to make someone responsible for the tool. This person should both manage and maintain the tool and have knowledge about how it works. Any necessary adjustments are executed by him or under his supervision and whenever the base stock levels have to be updated he should be part of that process. Changes made to the tool could be regarding input parameters of the fieldstock model. Because Stefan Baars, who works at the department of Hardware & Inbox Solutions, is already actively involved in monitoring the performance of the service engineers and he has sufficient knowledge of Excel, he is the most eligible person. Actual management and application of the tool should be allocated to a project group. Because the service engineers are under supervision by the department of Hardware & Inbox Solutions this project group should also be part of this department. However, because the responsibility for the total inventory investment lies with the department of Supply Chain Management it is important for both departments to cooperate closely and make agreements on the intended goals of the tool when implementing it. This relates closely to the topic of section 7.2.

7.2. Basis of support within Ricoh

As service engineers are currently held responsible for the second visits they cause and these represent one of the KPIs they are judged on, adequate inventory management is important for them. Therefore there might be reluctance among the service engineers to accept the outcome of the tool. If the tool designed in this research is implemented in a way that enforces higher level inventory control on the carstock of the service engineers, they can no longer be held responsible for the inventory management of their carstock. This would necessitate the removal of the KPIs related to inventory control to represent their lack of influence on service part inventory. Doing so will most likely cause engineers to lose interest in being actively concerned with inventory management. In accordance with management at Ricoh it is agreed that the best way to implement the tool is by giving it a supporting role. The service engineers would then
remain responsible for their carstock and the outcome of the tool could be used to assess the performance of the engineers with regard to this carstock. By setting new KPIs with regard to the maximum or average inventory investment and target fill rate performance, the engineers can be assessed and if necessary corrected with the use of the fieldstock model. This way engineers that manage their carstock inventory satisfactory can keep their autonomy, while the engineers that do not can be corrected and advised based on the inventory levels suggested by the tool.

Furthermore, responsibility for the lockerpoints should be centralized. Although guidelines exist on what should be stored there, responsibility for each lockerpoint is carried by one of several employees and engineers at Ricoh. To enable comprehensive management of these inventory locations, responsibility for its contents should lie with the group or person responsible for managing and applying the tool. This allows for rigorous decision making based on actual historical demand.

To get insight into the impact of real-life implementation of the tool, it should first be piloted on a small group of engineers. By doing this the actual performance when applying the tool in real-life can be monitored and verified making it possible to recognize any problems or required adjustments before implementing it on a large scale.

### 7.3. Limitations

Although there is no reason to think others regions would give different results, it is important to note that the results and conclusions presented in this research have been based on data of a single lockerpoint region, consisting of one lockerpoint and 16 engineers. This might hinder generalizability of the conclusions with regard to other lockerstock regions within Ricoh. The fieldstock model itself is however applicable to any region as long as the assumptions are met.

The problem overview presented in section 1.3 discussed how service part usage is sometimes incorrectly registered into the information system. The extent of the problem is currently being investigated and initial results show that more than 30% of the registered inventory value has in fact been incorrectly registered. Although it is unclear how this exactly happens, it seems to relate to the proficiency with which engineers are able to use the hand terminals with which service part inventory changes are registered. The problem can be detrimental for the accuracy of the demand and inventory information and therefore seriously limit any success achieved from performing inventory control based on this information. Therefore, to be able to use the tool designed in this research, dealing with this part registration issue is of importance and until then it seriously limits any inferences made based on demand and inventory information. This
should be done by determining the exact issues the service engineers encounter when using the hand terminals and providing additional training based on the identified issues.

This research assumes that when an engineer is not able to fulfil demand from his own carstock, a lockerpoint is visited, enabling them to fulfil demand within the first visit. In real-life it might however not always be possible for an engineer to visit a lockerpoint before the workday ends or before the SLA is breached. This depends on the time at which the customer is visited, the time required to repair the machine, the SLAs itself and the proximity to the lockerpoint. This makes the proposed first visit fill rates calculated by the fieldstock model an upper bound.

The size of the parts is calculated using the weights of the service parts. As sizes were available for only 46 service parts and weights for all service parts, a conversion factor was calculated. The pitfalls of doing so are that the size of extremely large parts can easily be underestimated and the high weight of some of the denser parts can cause an overestimation of the size of those parts. Because the results showed that the storage capacity of the fieldstock locations is a limiting factor for the inventory optimization, more research on the validity of using the service part sizes to determine service part volumes should be done. It is unclear how great the influence of the inaccurateness of the service part sizes really is and this might cause the tool to over capacitate the available storage space as some service parts might be much larger than assumed based on the volumes calculated using the service part weights.
8. Conclusions and recommendations

The reason for conducting this research is that because of the lack of rules in place to guide inventory management, Ricoh is not able to make informed decisions on how to control inventory. As inventory levels at Ricoh are thought to be too high, Ricoh is interested in finding out how the inventory levels can be determined while considering both supply chain costs and fill rate performance. This led to the following research assignment:

"Develop a tool to determine the optimal fieldstock inventory levels and supply chain costs given a desired service level taking into account storage capacity restrictions for a service part distribution system with dynamic and static fieldstock locations."

The main conclusions are presented in section 8.1, followed by section 8.2 which discusses the recommendations. Lastly the theoretical contribution of this research is discussed.

8.1. Main conclusions

This research assignment led to the development of the fieldstock model which can be used to determine close-to-optimal inventory levels while minimizing supply chain costs given a target fill rate performance. The fieldstock model has been tested in a case study executed at Ricoh Netherlands for the situation of a single lockerpoint region consisting of 16 engineers and one lockerpoint. Based on that case study the following conclusions have been drawn:

- The fieldstock model developed in this research can assist with service part inventory management and give insight into the relationship between the inventory levels and the cost and fill rate performance. The model can support decision making and allows Ricoh to analyse different scenarios with regard to changes in the cost parameters and service part fulfilment, with the goal of determining the consequences of such changes. The results show that cost and fill rate performance improvements can be achieved.

- Given the cost structure at Ricoh, the cost optimal solution reaching a 99,6% fill rate performance, due to the high costs related to a second visit. This shows that having sufficient inventory is of importance to prevent second visits and realize as low as possible supply chain costs.

- Based on the case study, it is found that the storage capacity restricts the cost optimal solution from being achieved. Results show that 13 of the 16 engineers were found to have insufficient storage capacity, with the important note that three out of the remaining four engineers drive larger vehicles with significantly more trunk space. Increasing the storage capacity was found to cause supply chain costs (including the
additional costs of using these larger vehicles) to be reduced by 13%. This shows that increasing the storage capacity is justified from a cost perspective.

- The fieldstock model was tested by determining the consequences of using the model to update the inventory base stock levels at different frequencies over a period of 3 years and the results showed that updating the base stock levels once a year is best both with regard to the supply chain costs and the fill rate performance.

- Considering seasonality for the review period of 6 months using Holt-Winters was found not to contribute to improved cost or fill rate performance compared to those achieved for the review period of 6 months using SMA, given the dataset used in this research.

### 8.2. Recommendations

Based on this research and the conclusions several recommendations can be made.

- Although results show that cost and fill rate improvements can be achieved by using the fieldstock model, inventory management should not solely rely on it. If the tool is implemented in a way that enforces higher level inventory control on the carstock of the service engineers they would lose most of the responsibility for their inventory and therefore also their accountability. This will most likely result in a loss of involvement with inventory management. By giving the tool a supporting role in monitoring the performance of service engineers more closely, this can ensure keeping them engaged in actively optimizing inventory management. By setting new KPIs with regard to a maximum or average inventory investment and a target fill rate performance based on the fieldstock model, the engineers can be assessed and if necessary corrected. This way engineers that manage their carstock inventory satisfactorily can remain autonomous, while engineers that do not can be advised and even corrected based on the tool.

- As findings suggest increasing the fieldstock inventory levels for Ricoh Netherlands can reduce costs while Ricoh Europe is aiming at lowering inventory, further research into the consequences of inventory management on the entire supply chain and the related costs can shed light on these contradictory conclusions. This would require an integral analysis of the entire distribution network.

- As the fieldstock model suggests a solution for which about 25% of demand is fulfilled from the lockerpoint, using the lockerpoints to store inventory seems to be justified. However, currently no information on actual usage from the lockerpoints is available, making it difficult to determine whether service engineers really make use of them. Service part usage from the lockerpoints should therefore be monitored in the future to help justify the use of lockerpoints. This will also help to determine which service
engineers visit which lockerpoints, allowing inventory management at the lockerpoints to become more accurately adapted to the actual demand experienced there.

- The problem of incorrect part registration should be solved because it seriously limits any success achieved from performing inventory control based on this information.

- To enable comprehensive management of these inventory locations, responsibility for its contents should lie with the group or person responsible for managing and applying the tool as consideration of demand experienced by the service engineers can provide good insight into what should be stored at a lockerpoint. This is emphasized by the fact that the fieldstock model uses the lockerpoint to store the more expensive and voluminous service parts.

- As mentioned in section 1.3 which discussed the problem overview, the skill distribution is a topic that closely relates to the service parts inventory levels. Although this topic was not researched in this paper, limiting the number of different skills that service engineers are trained on, can limit the variety of service parts for which a service engineer experiences demand. This could reduce the diversity in service part demand allowing for a lower diversity of service parts in inventory and lower total inventory. As this might come at the cost of lowering planning flexibility, further research should be done to determine whether the benefits regarding inventory management outweigh this downside.

8.3. Theoretical contribution

In this research a method is designed to determine service part base stock inventory levels for an after sales service system and there are several theoretical contributions.

This research considers a service part distribution system that consists of stock locations which experience direct customer demand and stock locations that only experience demand from other stock locations. The model can determine base stock inventory levels under storage capacity restrictions, with the goal of achieving a target fill rate performance and as low as possible total supply chain costs. The method is based on Kranenburg (2006) which tested the model for a review period of one year based on one demand forecasting method, whereas this research investigates the consequences of updating the base stock levels at different frequencies and two different demand forecasting methods, showing that considering seasonality did not increase performance and using review periods shorter than a year did not either. Although Rijk (2007) also considered storage capacity restrictions, that paper did not consider the actual service part sizes causing the model to ignore cost improvements per unit of volume which are of importance when storage capacity is a serious restriction.
Bibliography


Appendix A. Regions and Service Engineers

Currently, there are 425 registered Field Employees at Ricoh Netherlands. Although the majority of this group functions as a field (service) engineer, there are a number of different job descriptions covered by the term field employee. There are eight different categories that can be distinguished and five of those groups respond to service requests; Office Printing (OP), Production Printing (PP), Customer Support, Guidion and Solutions. Service engineers from the group Implementation sometimes use service parts during installation. The other groups focus on different tasks and do not carry any carstock. Customer Support refers to engineers that are dedicated to a specific customer and these engineers use stock located at the customer. Onsite engineers are like field engineers and are trained to repair printers, whereas customer support engineers are only allowed to replace cartridges, refill paper and solve minor incidents such as a paper jam. Guidion engineers are external engineers and most of them started working for Ricoh as of December 2013. Because little demand data is available for these engineers, these are not considered in this research.

The 350 service engineers that performed service during the period from the 1st of July 2013 until the 31st of December 2013 installed one or more service parts during 41.654 service visits, in total replacing 139.227 service parts. Of those visits, 7.278 visits concerned a return to fit parts, during which 20.869 service parts were replaced. In table A1 the different groups of engineers are compared with regard to their stockout rates. Table A2 shows some characteristics for OP and PP related service visits for the four regions. The OP group represents almost 70% of total part demand in the Netherlands and more than 21% of total part demand in the Netherlands occurs for OP machines in the South East.

<table>
<thead>
<tr>
<th>SE groups</th>
<th>Number of SEs</th>
<th>Number of service visits during which service parts were installed</th>
<th>Total demand for parts</th>
<th>Number of parts installed during a return to fit parts</th>
<th>Average stockout %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cust Supp</td>
<td>21</td>
<td>590</td>
<td>2150</td>
<td>50</td>
<td>2,33%</td>
</tr>
<tr>
<td>Guidion</td>
<td>7</td>
<td>36</td>
<td>90</td>
<td>3</td>
<td>3,33%</td>
</tr>
<tr>
<td>Implementation</td>
<td>24</td>
<td>1.042</td>
<td>3.773</td>
<td>135</td>
<td>3,58%</td>
</tr>
<tr>
<td>OP</td>
<td>202</td>
<td>31.284</td>
<td>97.678</td>
<td>16.898</td>
<td>17,30%</td>
</tr>
<tr>
<td>PP</td>
<td>69</td>
<td>8.385</td>
<td>34.727</td>
<td>3.722</td>
<td>10,72%</td>
</tr>
<tr>
<td>Solutions</td>
<td>27</td>
<td>317</td>
<td>809</td>
<td>61</td>
<td>7,54%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>350</td>
<td>41.654</td>
<td>139227</td>
<td>20.869</td>
<td>14,94%</td>
</tr>
</tbody>
</table>

Table A1. Stockout rate per SE group during July 1st 2013 until December 31st 2013.
<table>
<thead>
<tr>
<th>Region/Machine group</th>
<th>Part Demand</th>
<th>Percentage of Part Demand</th>
<th>Number of installed machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East OP</td>
<td>21511</td>
<td>15.44%</td>
<td>27477</td>
</tr>
<tr>
<td>North East PP</td>
<td>8339</td>
<td>5.99%</td>
<td>172</td>
</tr>
<tr>
<td>North West OP</td>
<td>22665</td>
<td>16.27%</td>
<td>25820</td>
</tr>
<tr>
<td>North West PP</td>
<td>9890</td>
<td>7.10%</td>
<td>1019</td>
</tr>
<tr>
<td>South East OP</td>
<td>29433</td>
<td>21.13%</td>
<td>27539</td>
</tr>
<tr>
<td>South East PP</td>
<td>8078</td>
<td>5.80%</td>
<td>272</td>
</tr>
<tr>
<td>South West OP</td>
<td>24159</td>
<td>17.34%</td>
<td>26864</td>
</tr>
<tr>
<td>South West PP</td>
<td>8420</td>
<td>6.04%</td>
<td>264</td>
</tr>
<tr>
<td>Rest*</td>
<td>6801</td>
<td>4.88%</td>
<td>444</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>139.296</strong></td>
<td><strong>100.00%</strong></td>
<td><strong>109871</strong></td>
</tr>
</tbody>
</table>

*Table A2. Characteristics per region and machine group. *this refers to item usage by SEs from other groups*
Appendix B. Algorithms to solve the model

Decoupling Algorithm

The decoupling algorithm assumes a given configuration of base stock levels, i.e. a given set of $S_i$, for $i \in I$, and a known direct customer demand equal to $M_{i,j}$ for $i \in I$ and $j \in J$. For any configuration the probability of not being able to fulfil demand when it occurs can be calculated using the Erlang loss model. This uses the steady state Markov chain to represent the inventory position at a fieldstock location as a queuing system. This queuing system has a number of available servers and experiences arrivals of customers that need to be serviced. The occupation rate of a single server, denoted by $\rho$, is equal to the arrival rate multiplied by the service time. This is easily understood when choosing an arrival rate of 1 arrival per 2 hours and a service time of 2 hours. Then, $\rho = \frac{1}{2} \times 2 = 1$. Every two hours an arrival occurs at the server after which it takes the server 2 hours to service that arrival (or customer). This means the server is fully occupied, on average. Due to variations in the arrival process, this does not mean that every new arrival can immediately be serviced. In fact, when the occupation rate is equal to 1, the waiting line will grow continuously due to variations in demand. When there are $n$ servers available, the following notation is used for the probability of not being able to service a new arrival (called the loss probability of the Erlang loss model):

$$L(n, \rho) = \frac{\rho^n / n!}{\sum_{x=0}^{n} \rho^x / x!} \tag{12}$$

When choosing $\rho = 1$ and $n = 1$, the loss probability is 0.5. This means 50% of the arrivals can be serviced immediately.

When applying the Erlang loss model to the inventory situation of SKU $i$ at fieldstock location $j$, each server represents one item of SKU $i$. The total number of available servers then represents the total available inventory for SKU $i$. The arrival rate is equal to the demand rate $M_{i,j}$ which means that whenever a demand of one occurs, a server is occupied. The rate at which a server becomes available is then determined by the replenishment time. This enables the calculation of loss probability (i.e. the probability of not meeting demand when it occurs) at each of the fieldstock locations, by using only their base stock levels and demand rates. The Erlang loss model is graphically depicted in figure B1. Again, the demands are considered as arrivals and the items in the pipeline (i.e. items which have been ordered but not yet delivered) are considered to be occupied servers in the queuing model. Whenever an item is delivered, a server becomes available again.
Figure B1 shows the inventory position in the red squares for item $i$ at fieldstock $j$ with a maximum of $S_{i,j}$ available servers. The inventory position decreases by one at a rate of $M_{i,j}$ and increases by one at a rate of $\frac{S_{i,j} - n}{t^{reg}}$ because every time a service part is taken from the inventory, a new item is immediately ordered at the ESPC and received $t^{reg}$ time later.

Decoupling the carstocks from the lockerstock location

The fill rate for item $i$ at carstock $c$ can be calculated using the Erlang loss model: $\beta_{i,c}(S_i) = 1 - L(S_{i,c}, M_{i,c} t^{reg})$. The exchange of service parts from a lockerpoint to a carstock occurs when a customer demand at carstocks $c$ occurs, while that carstock is not able to fulfil that demand directly from stock. This demand then flows over to lockerpoint $l$. Again it is assumed that the demand that flows over to the lockerpoint follows a Poisson process. Because this demand occurs only when a carstock is out of stock, it is lumpier in reality. However, for low demand rates this assumption seems reasonable.

As stated before, there is no direct customer demand experienced at the lockerpoint. The indirect demand experienced at the lockerpoint is denoted by $\bar{M}_{Ul} = \sum_{c \in C} \left(1 - \beta_{i,c}(S_i)\right) M_{i,c}$. The fill rate for item $i$ at lockerpoint $l$ can then be calculated: $\bar{\beta}_{i,l}(S_i) = 1 - L(S_{i,l}, \bar{M}_{Ul} t^{reg})$.

Because $\alpha_{i,l,c}(S_{i,c}) = 0$, $\beta_{i,l,c}(S_{i,c}) = 1 - \beta_{i,l}(S_i)$. Now $\alpha_{i,c,l}(S_i)$ can be calculated by $\alpha_{i,c,l}(S_i) = \left(1 - \beta_{i,c}(S_i)\right) \beta_{i,l}(S_i)$. Finally, $\beta_{i,c}(S_i)$ can be calculated.
The steps necessary to decouple the carstocks from the lockerpoint are now described mathematically.

**Step 1** For all carstocks $c \in C$, $\beta_{i,c}(S_i) := 1 - L(S_{i,c}, M_{i,c}^{reg})$

**Step 2** For lockerpoint $l$ determine $\bar{M}_{i,l} = \sum_{c \in C} \left(1 - \beta_{i,c}(S_i)\right)M_{i,c}$

**Step 3** For lockerpoint $l$ determine $\beta_{i,l}(S_i) = 1 - L(S_{i,l}, \bar{M}_{i,l})^{reg}$ and $\beta_{i,l}^{em}(S_i) = 1 - \beta_{i,l}(S_i)$

**Step 4** For all carstocks $c \in C$, determine $\alpha_{i,c,l}(S_i) := \left(1 - \beta_{i,c}(S_i)\right)\beta_{i,l}(S_i)$

**Step 5** For all carstocks $c \in C$, determine $\beta_{i,c,l}^{em}(S_i) := \left(1 - \beta_{i,c}(S_i)\right)\beta_{i,l}^{em}(S_i)$

**Solving algorithm**

The cost increase achieved when increasing the base stock level for SKU $i$ at fieldstock $j$ by one is denoted by $\Delta C(i,j) = C_i(S_{i,j} + 1) - C_i(S_{i,j})$. The cost increase per unit volume is then equal to $\Delta C(i,j)/V_i$. To calculate the performance change per unit cost per unit volume achieved by increasing the base stock level for SKU $i$ at fieldstock $j$ by one, the total positive difference between the target and the current performance (for $\forall i \in I$, $\forall j \in J$) is compared to the total positive difference between the target and the new performance (for $\forall i \in I$, $\forall j \in J$). If the base stock level $S_{i,j}^{'}$ for SKU $i' \in I$ at fieldstock $j' \in J$, is increased by one this performance change is calculated as follows:

$$\Delta \beta_{i,j}^{total}(i',j') := \sum_{j \in J \backslash L} \left[ \beta_{i}^{obj}_{i,j} + \sum_{i \in I} \frac{m_{i,j}}{M_j} \beta_{i,l}^{total}(S_{i,j}) \right]^{+}$$

$$- \sum_{j \in J \backslash L} \left[ \beta_{i}^{obj}_{i,j} + \sum_{i \in I \backslash \{i'\}} \frac{m_{i,j}}{M_j} \beta_{i,l}^{total}(S_{i,j}) - \frac{m_{i,j}}{M_j} \beta_{i,l}^{total}(S_{i',j}^{'} + 1) \right]^{+} \tag{13}$$

$[a]^{+} = \max\{0,a\}$.

Finally, the ratio

$$R(i,j) := \frac{\Delta \beta_{i,j}^{total}(i,j)}{\Delta C(i,j)/V_i} \tag{14}$$

For $i \in I$, $j \in J$ is defined as the decrease in distance to the set of feasible solutions per unit cost per unit volume. Mathematically, the heuristic can be described as follows.
Step 1 Set $S_{i,j} := 0$, $\forall i \in I$, $\forall j \in J$.

Step 2 For each combination of SKU $i \in I$ and fieldstock $j \in J$, while $\sum_{t \in T} V_t (S_{0,t}) + V_t \leq V_{t}^{\max}$:

Step 2-a Calculate $\Delta C(i,j)/V_i$

Step 2-b While $\min \{ \Delta C(i,j) \} \leq 0$:
   1. Determine $i$ and $j$ for which $\Delta C(i,j)/V_i \leq \Delta C(i,j)/V_i$ for $\forall i \in I/\{i\}$, $\forall j \in J/\{j\}$
   2. Set $S_i := S(i,j) + 1$.
   3. Repeat step 2.

Step 3 For each combination of SKU $i \in I$ and fieldstock $j \in J$, while $\sum_{i \in I} V_i (S_{i,j} + 1) \leq V_{i}^{\max}$:

Step 3-a Calculate $R(i,j)$.

Step 3-b While $\max \{ R(i,j) \} > 0$:
   1. Determine $i$ and $j$ for which $R(i,j) > R(i,j)$ for $\forall i \in I/\{i\}$, $\forall j \in J/\{j\}$
   2. Set $S_i := S(i,j) + 1$.
   3. Repeat step 3.
Appendix C. Poisson distributed demand

Montgomery & Runger (2007) describe a procedure to test the hypothesis that a certain distribution will represent the data satisfactory. This procedure is called a goodness-of-fit test and it is based on the chi-square distribution. The procedure uses discrete data and arranges it into several value classes. For each class the observed frequency (the number of times weekly demand falls within this class) is determined based on the data. Based on the hypothesized distribution an expected frequency is also calculated for each class. The chi-square statistic is then used to determine whether the hypothesized distribution differs significantly from the actual distribution. The hypothesis that the distribution of the population is the hypothesized distribution is rejected if the chi-square test statistic is found to be significant.

The assumption of Poisson distributed demand is checked for data from the 16 engineers considered in the case study. Because daily demand is too low for most service parts, weekly demand data was used. Because of the presence of seasonality in demand, the assumption is checked for 3 half year periods starting at the 1st of May 2012, the 1st of November 2012 and the 1st of May 2013. The sample size for each service part is 26. According to Montgomery & Runger (2007) the expected frequency for each class should be at least 3. The minimum number of classes should be equal to three. Based on these requirements, data on 148 service parts was available. For 78% of these service parts it was found that the chi-square test statistic was non-significant using a significance level of 1%. This means it is not possible to reject the hypothesis that demand is Poisson distributed for 115 service parts.
Appendix D. Forecast method

Adjusted Multiplicative Holt–Winters method

The Holt–Winters Multiplicative forecasting method consists of two stages. The first stage is to determine initial values for the two components. The second stage consists of updating these values by considering newly available data. The initialization and updating formulas used are taken from Chatfield & Yar (1988). The demand forecast is given by:

\[ \hat{y}_{t+1} = m_t \cdot c_{t-s+1} \]  \hspace{1cm} (15)

Updating functions:

\[ m_t = a_0 \frac{y_t}{c_{t-s}} + (1 - a_0)m_t \]  \hspace{1cm} (16)

\[ c_t = a_1 \frac{y_t}{m_t} + (1 - a_1)c_{t-s} \]  \hspace{1cm} (17)

Initialization functions:

\[ m_0 = \sum_{t=1}^{s} \frac{y_t}{s} \]  \hspace{1cm} (18)

\[ c_0 = \frac{m_0}{m_0} \]  \hspace{1cm} (19)

The ratio used to forecast demand at the SKU level:

\[ \text{ratio}_t^f = \frac{\hat{y}_t^f}{y_t^f} \]

Where

- \( y_t \) = actual aggregated demand for period \( t \) (at service part category level)
- \( \hat{y}_{t+1} \) = the aggregated demand forecast for period \( t+1 \)
- \( m_t \) = the aggregated demand level for period \( t \)
- \( c_t \) = a seasonal index for period \( t \)
- \( s \) = number of periods per season (for this research 4 or 2 for quarterly and half yearly, respectively)
- \( k = 1, 2, \ldots, s \) (each period has its own initialization value for \( c_0 \))
- \( a_0 \) = smoothing parameter for the level
\( a_t \) = smoothing parameter for the seasonal factor

\( \text{ratio}_t^r \) = forecasting ratio for service part category \( r \) for period \( t \)

The second stage requires a smoothing constant between 0 and 1 for the demand level and one for the seasonal indices. This constant determines how much weight is given to the estimation made with the new data and how much weight is given to the previous estimate. A smoothing constant of 1 suggests the new value for the component is completely based on the new data, while the previous estimate is not taken into consideration. By minimizing the sum of the squared forecasting errors (Chatfield & Yar, 1988) these constants can be determined. The smoothing constants found for the two half year and quarterly review periods are shown in table D1. Ideally, smoothing constants should be between 0,02 and 0,2 according to Chatfield & Yar (1988). The smoothing constants presented in table D1 do not meet these guidelines. This suggests that this forecasting method might not be appropriate for these data. The reason for this is that the seasonality effect differed a lot from year to year. To see whether the Holt-Winters forecasting method is able to achieve improvements compared to the SMA method it will still be tested on the fieldstock model.

<table>
<thead>
<tr>
<th>Service part category</th>
<th>Half year review period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smoothing constant</strong></td>
<td>( a_0 )</td>
</tr>
<tr>
<td>Charge rollers</td>
<td>0</td>
</tr>
<tr>
<td>Drums</td>
<td>0,953</td>
</tr>
<tr>
<td>PCUs</td>
<td>1</td>
</tr>
<tr>
<td>Normal parts</td>
<td>0</td>
</tr>
</tbody>
</table>

*Table D1. Smoothing constants for the half year review period*