

Eindhoven, October 2016

**Modelling the Use of  
Car Stocks to Evaluate  
the Effect on Logistics Costs**

by  
G.W. Alkema

BSc. Industrial Engineering – TU/e  
Student identity number 0791779

in partial fulfilment of the requirements for the degree of

**Master of Science  
in Operations Management and Logistics**

**Public version**

Supervisors:  
Prof.dr.ir. G.J.J.A.N. van Houtum, TU/e, OPAC  
Dr. H. Blok, TU/e, OPAC  
Dr.ir. J.J. Arts, TU/e, OPAC  
Ir. J. van der Wal PDEng., Royal Philips N.V.



TU/e School of Industrial Engineering.  
Series Master theses Operations Management and Logistics

Subject headings: car stock, corrective maintenance, greedy heuristic, logistics costs, service process, spare parts distribution network



# Abstract

---

In this research project, we analyze the effects of the introduction of car stocks on logistics costs in the current service process of Royal Philips. A new service process is proposed, that includes spare parts inventory holding at the cars of Field Service Engineers (FSEs). The main cost buckets that cause the change in logistics costs at the introduction of car stocks compared to the current service process are defined. Logistics costs are defined as all costs related to spare part handling, inventory holding, spare part transportation, and FSEs. We develop a cost model to determine the costs for the defined cost buckets for both the current and proposed service process, under given basestock levels for the car stocks. An optimization algorithm is developed to, given the car size of the FSE, obtain close-to-optimal basestock levels that minimize total logistics costs, with corresponding car stock review period length and number of needed full-time FSEs.

# Preface

---

This thesis is the result of my graduation project, the last stage of my master Operations, Management & Logistics at the Eindhoven University of Technology. I would like to thank a few people that have been essential in completing this research.

I had the opportunity to conduct this research at Philips in Best. I would like to thank my company supervisor, Japke van der Wal. Thank you for guiding me around within the SPS department, helping me with the scoping of my project, and giving me lots of freedom in conducting the research. I would also like to express my gratitude to all colleagues of the SPS department that helped me with my overload of questions.

Furthermore I would like to thank my first university supervisor, Geert-Jan van Houtum. Your great knowledge in the field of service logistics helped me a lot, especially during scoping my research, and structuring and finalizing this thesis. I would also like to thank my second university supervisor, Herman Blok. Your mathematical insights and specific feedback helped me to improve this thesis. Additionally, I would like to thank my third university supervisor, Joachim Arts, for completing my master thesis assessment committee.

This thesis not only concludes this graduation project, but also my seven years of student life. Two years of Tilburg, four-and-half years of Eindhoven, and half a year of Taipei brings me to the point where I am now. Many thanks to all my friends that helped creating a lot of great memories, of which the Industria Congres and exchange semester in Taipei clearly were the most awesome ones.

Last but not least, I would like to thank my parents, sister, and brother for their constant support, all in their own way. Finally, my thanks go out to Suzanne. Thank you for making me laugh, your mutual weirdness, but most of all for being the best girlfriend I could wish for!

*Geert Alkema*

# Executive Summary

---

This master thesis, conducted at the Service Parts Supply Chain (SPS) department of Royal Philips, describes the effects of the introduction of spare parts inventory holding at the cars of Field Service Engineers (FSEs) on logistics costs in the current service process of Royal Philips. Logistics costs are defined as all costs related to spare part handling, inventory holding, spare part transportation, and FSEs.

## Current Service Process (Scenario 0)

Royal Philips distinguishes six main product modalities: CT, DXR, iXR, MR, PCMS, and US. Together with all machines in these modalities, service contracts are sold. These contracts secure an agreed response time at failure of a machine and uptime of the machine. At the unexpected failure of a machine, so-called *corrective maintenance* is performed. Philips first tries to solve the issue remotely via mail or phone. If this is not possible, an FSE will be sent to the customer site to detect the problem. If the needed maintenance does not require a spare part, the FSE fixes the problem immediately. Otherwise, the FSE orders the required spare part and, in general, installs the spare parts the next business day. We scoped this research on this latter type of service calls, which thus always needs two customer site visits from the FSE. SPS runs the worldwide (mainly) single-location spare part supply chain, where outbound orders are sent from the Regional Distribution Centre (RDC) by the UPS express service, which delivers the spare parts the business day after ordering. The spare parts are sent to either the customer site or a Pick-Up Drop-Off point (PUDO), which both cause on average the same amount of spare part collecting time for the FSE. SPS pays a fixed in- and outbound handling cost at the RDC, outbound spare part transportation costs and PUDO handling costs, all per orderline. Furthermore, a fixed hourly FSE rate is paid which includes both the FSEs salary and car-related costs.

## Service Process with Car Stock (Scenario 1)

A predefined set of car stock spare parts will be assigned to each FSE, based on the modality and country the FSE is operating in. In case of a corrective maintenance call, the FSE visits the customer site to detect the cause of the failure. If the needed maintenance requires a specific spare part, and that part is available in the car stock, then the FSE will install the spare part immediately. The FSE immediately orders a new spare part for the car stock. If the defective part is not available in the car stock, then the FSE will follow the service process from Scenario 0, and thus will order the needed spare part and will install the part the next business day. Due to the requirement of bigger FSE cars, the hourly FSE travel costs will increase. The car stocks of FSEs will be replenished using PUDOs, since these locations are not customer-related. To prevent many extra PUDO visits for FSEs, car stock replenishment orders will be delivered using a replenishment cycle with a fixed length. These replenishment orders will be delivered by the UPS economy service, which is less expensive than the UPS express service, but has a slower leadtime of three business days. To minimize FSE travel time for the replenishments of the car stock, the replenishment orders will be sent to the PUDO which is the closest to the FSEs home address.

## Differences between Scenario 0 and Scenario 1

Four main cost buckets that cause the change in logistics cost in Scenario 1 compared to Scenario 0 are defined: outbound spare part transportation costs, PUDO handling costs, FSE costs, and car stock inventory holding costs. Compared to Scenario 0, outbound transportation cost decrease in Scenario 1, since car stock spare parts are delivered by the UPS economy service, instead of the more expensive UPS express service. Since car stocks are replenished via PUDOs, the PUDO handling costs will increase. FSE costs will decrease due to the save in customer site visits, but will increase caused by the extra PUDO visits for the car stock replenishments, and the increase in the FSE hourly travel rate. Car stock inventory holdings costs is a new cost bucket introduced for Scenario 1.

## Conclusion

A cost model is developed, that determines the costs of the defined cost buckets for both Scenario 0 and, under given basestock levels for the car stock, Scenario 1. Furthermore, an optimization algorithm is developed to, given the car size of the FSE, obtain close-to-optimal basestock levels that minimize total logistics costs, with corresponding car stock review period length and number of needed full-time FSEs. Based on the implementation of this algorithm on the Philips orderlines in 2015, we draw the following conclusions:

- The introduction of car stocks causes a decrease in total logistics costs for all modalities, except for the modality MR in France, which shows a minor increase in logistics costs. Total annual absolute and relative saving are █████ Million EUR and 3,4% respectively. The highest absolute decrease in total costs were found for the DXR modality, especially in Germany and the United Kingdom, with savings up to █████ (20,1%) and █████ Million EUR (8,0%) per year respectively.
- The decrease in logistics costs of Scenario 1 compared to Scenario 0 is caused by the major decrease in FSE costs. Although car stock inventory holdings costs is a new cost bucket in Scenario 1 compared to Scenario 0, the increase of this cost bucket does not outweigh the decrease in FSE costs. Furthermore, we see that PUDO handling and outbound transportation costs have an almost neglectable effect on total logistics costs.
- The introduction of car stocks has a significant influence on the customer service rate for all countries and modalities, since if a car stock SKU is available at demand, an FSE can directly perform the needed maintenance, saving a second visit to the customer site the next business day. The percentage of single-visit service calls in Scenario 1 varies between 9,9 and 46,6% for the different countries and modalities, with an average of 18,5%.
- Based on the sensitivity analysis on the maximum storage capacity of an FSE car, we can conclude that the biggest 'bang' is made at the introduction of the first m<sup>3</sup> of car stock for all modalities. Furthermore, it was found that the main trade-off of the introduction of car stocks is the decrease in FSE costs compared to the increase in car stock inventory holding costs.
- Based on the sensitivity analysis on the car stock review period length, we can conclude that there exists a single optimal review period length, due to the decreasing effect on car



stock inventory holdings costs for longer review period lengths and the found tipping point in FSE costs, which makes both too short and too long review periods not favorable.

### **Recommendations**

Our main recommendation is to perform a pilot implementation of car stocks for the modality DXR in either Germany or the United Kingdom, since this modality and these countries clearly showed the highest absolute savings. Second, we recommend to also conduct research on the introduction of car stocks for the emergency taxi deliveries. Third, since we concluded that the outbound spare part transportation costs have an almost neglectable influence on total logistics cost, it would be interesting to research what the effect is of the use of the express transportation instead of the economy transportation mode for the car stock replenishment. This would cause slightly higher transportation costs, but decreases the spare parts in the carstock order pipeline, and thus increases the SKU fill rate for car stock SKUs. Last, we recommend to gain more insights in the current FSE process and corresponding costs such that a more accurate estimation of the change in FSE costs could be given.



# Contents

---

<b>Abstract</b>	<b>i</b>
<b>Preface</b>	<b>ii</b>
<b>Executive Summary</b>	<b>iii</b>
<b>List of Figures</b>	<b>ix</b>
<b>List of Tables</b>	<b>x</b>
<b>List of Abbreviations</b>	<b>xi</b>
<b>1 Introduction</b>	<b>2</b>
<b>2 Research Statement</b>	<b>4</b>
2.1 Company Background .....	4
2.2 Service Parts Supply Chain .....	5
2.3 Research Definition .....	5
2.4 Research Approach .....	7
2.5 Scope .....	7
<b>3 Current Service Process (Scenario 0)</b>	<b>10</b>
3.1 Service Contracts .....	10
3.2 Service Calls .....	10
3.3 FSEs .....	11
3.4 Spare Part Distribution .....	12
<b>4 Service Process with Car Stocks (Scenario 1)</b>	<b>16</b>
4.1 FSEs .....	16
4.2 Spare Part Distribution .....	17
<b>5 Differences Current and Car Stock Scenario</b>	<b>18</b>
5.1 Spare Part Transportation Costs .....	18
5.2 Handling Costs .....	19
5.3 FSE Costs .....	19
5.4 Inventory Holding Costs .....	19
5.5 Conclusion .....	20
<b>6 Cost and Optimization Model</b>	<b>22</b>
6.1 Introduction .....	22
6.2 Cost Formulas .....	22
6.3 Assumptions .....	26
6.4 Evaluation Car Stock .....	27
6.5 Optimization Problem .....	28
6.6 Convexity of Objective Function .....	29
6.7 Optimization Algorithm .....	32
<b>7 Implementation Optimization Algorithm</b>	<b>36</b>
7.1 Overall Analysis .....	36
7.2 Car Size Analysis .....	38
7.3 Review Period Length Analysis .....	40

<b>8</b>	<b>Conclusion</b>	<b>44</b>
8.1	Main Findings.....	44
8.2	Limitations.....	45
8.3	Recommendations.....	45
	<b>Bibliography</b>	<b>48</b>
	<b>Appendix A – Spare Part Orders per Maintenance Type</b>	<b>52</b>
	<b>Appendix B – PUDO-eligible SKUs</b>	<b>52</b>
	<b>Appendix C – CM Orderlines per Country</b>	<b>52</b>
	<b>Appendix D – CM Orderlines per Modality</b>	<b>52</b>
	<b>Appendix E – Car stock suitability per modality</b>	<b>52</b>
	<b>Appendix F – Full-time FSEs and overall FSE hours</b>	<b>52</b>
	<b>Appendix G – Denoted Variables</b>	<b>53</b>
	<b>Appendix H – FSE Hours per country and modality</b>	<b>55</b>
	<b>Appendix I – Variance of Order Quantities</b>	<b>55</b>
	<b>Appendix J – Minimum Number of FSEs in Scenario 1</b>	<b>55</b>
	<b>Appendix K – Logistics Costs of Scenario 0</b>	<b>55</b>
	<b>Appendix L – Logistics Costs of Scenario 1</b>	<b>55</b>

# List of Figures

---

Figure 1: Partial organizational structure of Philips .....	4
Figure 2: Partners of SPS .....	5
Figure 3: Current spare parts flow .....	14
Figure 4: Percentual decrease in costs of economy vs. express transportation.....	18
Figure 5: Car stock replenishment cycle.....	23
Figure 6: Flow diagram of the order pipeline stock $X_i$ .....	27
Figure 7: Normalized decrease in logistics costs per country and modality .....	36
Figure 8: Normalized decrease per cost bucket per modality .....	37
Figure 9: Percentage of single-visit maintenance service calls in Scenario 1 per country and modality.....	38
Figure 10: Total normalized decrease in logistics costs per modality .....	39
Figure 11: Normalized decrease per cost bucket per modality with car size of $3m^3$ .....	39
Figure 12: Normalized change in car stock inventory holding costs for Germany DXR .....	40
Figure 13: Normalized change in FSE costs for Germany DXR .....	41
Figure 14: Normalized change in PUDO handling costs for Germany DXR.....	41
Figure 15: Normalized change in spare part transportation costs for Germany DXR .....	42

# List of Tables

---

Table 1: Optimization algorithm .....	33
Table 2: Description of all denoted variables .....	54
Table 3: Variances of order quantities of all SKUs .....	55

# List of Abbreviations

---

AMEC	Global region, consisting of North- and South-America
APAC	Global region, consisting of Asia and Oceania
BIU	Business Innovation Unit
BR	Blue Room
CT	Computed Tomography
DXR	Diagnostic X-Ray Radiogrammetry
EMEA	Global region, consisting of Europe, the Middle-East, and Africa
FSE	Field Service Engineer
FSL	Forward Stocking Location
ICCP	In-Country Consolidation Point
iXR	Image Guided Therapy
KM	Key Market
LDC	Local Distribution Centre
MR	Magnetic Resonance Imaging
NEMO	No Engineer Material Order
PCMS	Patient Care & Monitoring Solutions
PUDO	Pick-Up Drop-Off location
RDC	Regional Distribution Centre
SPS	Service Parts Supply chain
US	UltraSound





# 1 Introduction

---

Together with all machines of Royal Philips, service contracts are sold. These contracts secure an agreed response time at failure of a machine and uptime of the machine. The service process covers all operations that are needed to fulfill these agreed service levels. This process works sufficiently, but is however expensive to operate. Especially for low-value parts it is questioned if a decrease in logistics costs would be possible. This creates the need for re-examination of the current strategy.

This master thesis describes both the qualitative and quantitative effects of the introduction of car stocks on logistics costs in the current service process of Royal Philips. Logistics costs are defined as all costs related to spare part handling, inventory holding, spare part transportation, and FSEs. In this context, we define car stock as the spare parts that a Field Service Engineer (FSE) keeps on stock in his/her car.

The remainder of this thesis is structured as follows. In the next chapter, we provide a background on both Royal Philips and the Service Parts Supply chain (SPS) department, at which this research is conducted. Furthermore, we define the problem statement, the research objective, research questions and research approach. Lastly, we define the research scope.

Chapter 3, 4, and 5 cover the qualitative part of this thesis. Chapter 3 introduces all components of the current service process of Royal Philips, which will be referred to as *Scenario 0*. In Chapter 4, we describe *Scenario 1*, which is the proposed new service process including car stocks. We conclude the qualitative part of this thesis in Chapter 5, by discussing the differences between both scenarios and defining the main cost buckets that drive the change in logistics costs in Scenario 1 compared to Scenario 0.

In Chapter 6 and 7, we perform a quantitative analysis on both Scenario 0 and Scenario 1. In Chapter 6, we describe a quantitative cost model to determine the total costs of the defined main cost buckets in Scenario 1. As explained in this chapter, Scenario 0 is a special case of Scenario 1, which makes the model applicable for both scenarios. Furthermore, we develop an optimization model and corresponding optimization algorithm that determines close-to-optimal basestock levels to minimize the total logistics costs per country and modality. In Chapter 7, we implement this algorithm, analyze the results, and furthermore perform a sensitivity analysis on the maximum storage capacity of the FSE cars and the review period length of the car stock.

The thesis concludes in Chapter 8, by providing the main findings and recommendations for both Royal Philips and future research.



## 2 Research Statement

---

This chapter provides an introduction on the conducted research. First, we describe the research context by providing a background on Royal Philips and the SPS department, at which the research is conducted. Then, the problem statement is formulated which leads to the definition of a research objective and corresponding research questions. Furthermore, the research approach and scope are defined.

### 2.1 Company Background

Founded in 1891, Philips quickly became one of the largest producers of electric incandescent light bulbs of Europe. Currently headquartered in Amsterdam, The Netherlands, it is nowadays known as one of the largest electronics companies in the world. The mission of Philips is ‘improving people’s lives through meaningful innovation’. By this innovation Philips strives to make the world healthier and more sustainable, as stated in their vision.

Since January 2008, Philips divides their activities in three main sectors: Healthcare, Lighting, and Consumer Lifestyle. In September 2014 it was announced that the sectors Healthcare and Consumer Lifestyle would merge into one company, Philips HealthTech, and split from the Lighting sector. Philips HealthTech, formally referred to as Royal Philips, focusses on the full spectrum of health: stimulating a healthy lifestyle, prevention of diseases, diagnosis, hospital treatment, and homecare.

In 2015, Philips HealthTech had approximately 55.000 employees and is globally present in over 100 countries. In that year, a profit of 16,25 billion EUR and net revenue of 1,70 billion EUR was achieved (Royal Philips N.V., 2016). In the remainder of this paper Philips HealthTech will be referred to as Philips.

Philips consists of four different business groups: Personal Health Businesses, Global Customers Services, Imaging Businesses, and Connected Care & Health Informatics. The Global Customers Services business group is split up into four Business Units: Global Education, Quality & Regulatory, Business Transformation & Operational Support, and Service Parts Supply Chain. The research is conducted at the latter business unit. This organization structure is illustrated in Figure 1.

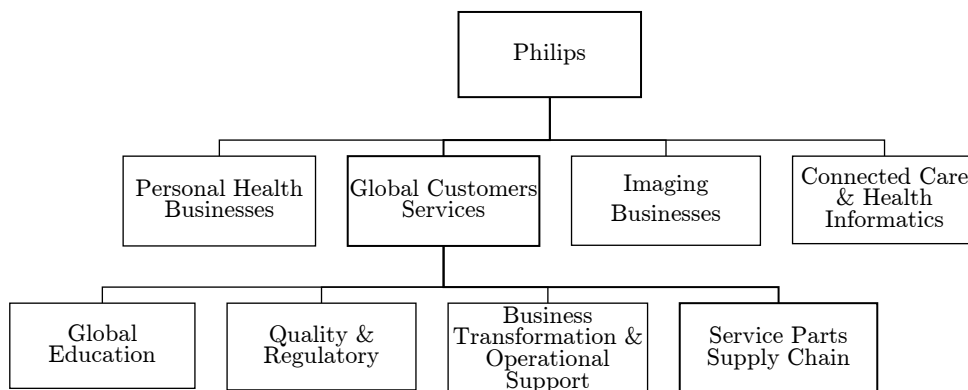


Figure 1: Partial organizational structure of Philips

## 2.2 Service Parts Supply Chain

The mission of SPS is to ‘improve people’s lives through reliable and cost effective delivery of high quality spare parts worldwide with an engaged workforce’. SPS is responsible to deliver every right spare part at the right place, time, and cost. It has a transaction volume and value of approximately one million orders and 1.800 million EUR per year respectively. The total spare parts inventory value is more than 600 Million EUR.

SPS is divided into eight teams: Customer Order Operations, Strategic Planning & Supply, Supply Chain Strategy & Architecture, Global Reverse Supply Chain, SPS Programs, Project Management, Lean Deployment, and Customer Demand & Fulfillment. This research is conducted within the latter team.

To achieve the agreed service levels in customers’ contracts, SPS works together with three external partners, illustrated in Figure 2. The transactional activities are outsourced to Accenture. Sanmina manages the reverse supply chain and UPS facilitates the global storage and is the main distribution partner. SPS coordinates these activities and is furthermore responsible for the global spare parts planning, to fulfil the agreed service levels of the machines of all modalities. This includes inventory planning at all warehouses and maintaining the spare parts distribution network to deliver spare parts to the customers.

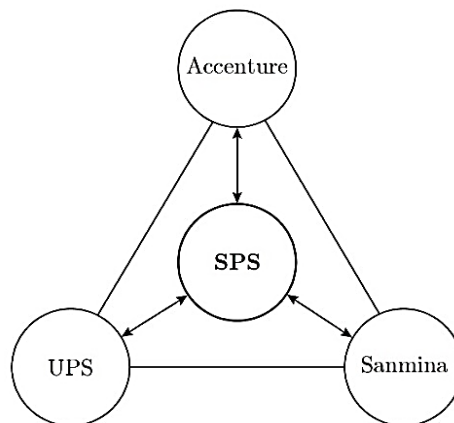


Figure 2: Partners of SPS

## 2.3 Research Definition

This section formulates the problem statement, which provides the basis for the subsequently defined research objective. To fulfil this research objective, we conclude the section with the research questions and approach.

### 2.3.1 Problem Statement

The current service process of Philips fulfills the agreed service levels of the service contracts. The process is however mainly designed for the optimal distribution of high-value parts, causing relatively high logistics costs for low-value parts.

Before 2007, SPS made use of car stocks for their Field Service Engineers (FSEs) to store mainly small and low-value spare parts. This however caused many impracticalities: it created lots of unwanted administrative hours for the FSEs and it was hard to centrally control the inventory in the cars. Therefore, in 2007 it was decided to store the stock as central as possible, by creating a mainly single-location distribution network for all three global regions: AMEC (consisting of North- and South-America), EMEA (consisting of Europe, the Middle-East, and Africa), and APAC (consisting of Asia and Oceania). In these distribution networks, spare parts are delivered from a Regional Distribution Centre (RDC) in the corresponding global region.

Nowadays the technology reaches much further, making it possible to avoid the extra administration for FSEs and to properly control the car stock spare parts. Furthermore, for example Rijk (2007) describes that a proper car stock model can save logistics costs. This creates the need from Philips to investigate the effect of re-introduction of car stocks for FSEs on logistics costs of the whole service process. This does not only include logistics costs related to spare parts distribution, but also related to the FSE process.

### 2.3.2 Research Objective

Based on the described problem statement, the following research objective is formulated:

*Modelling the use of car stocks in the current Philips service process to evaluate the effect on logistics costs.*

This objective is two-folded: the research will model the logistics costs of the Philips service process for both the current situation without (Scenario 0), and the new situation with car stocks (Scenario 1), and furthermore evaluates in which way the introduction of car stocks influences the logistics costs of the Philips service process.

### 2.3.3 Research Questions

To fulfil the stated research objective, the following research questions are formulated:

- 1. What are the main cost buckets of the current service process that will change if car stocks are introduced?*
- 2. What are the main characteristics that influence a Stock Keeping Unit (SKU) to be eligible to be placed in a car stock?*
- 3. Which and how many SKUs should be placed per country and product modality to optimize the use of car stocks and therefore minimize logistics costs of the Philips service process?*
- 4. How will the main cost buckets of the current Philips service process change if car stocks are introduced?*
- 5. What is the influence of the different input parameters of both models on the logistics costs of the Philips service process?*

## 2.4 Research Approach

To answer the defined research questions, we first describe the service process of both Scenario 0 and Scenario 1. Furthermore, we highlight the differences between these scenarios to define the main cost buckets that will cause the change in logistics costs at the introduction of car stocks. We then develop a cost model to determine the costs for the defined cost buckets for both Scenario 0 and Scenario 1. Lastly, we develop an optimization model and corresponding optimization algorithm that determines close-to-optimal basestock levels to minimize the total logistics costs per country and modality. The optimization algorithm is based on the multi-item, single-location inventory model with the extension of emergency shipments as described in Chapter 2.9 of Van Houtum and Kranenburg (2016), and will be implemented in Matlab.

Based on the found logistics costs of the service processes of both scenarios, we will perform an analysis on the differences between both scenarios. Lastly, we perform a sensitivity analysis on the maximum storage capacity of the FSE cars and the review period length of the car stock, to gain insights into the effects of these parameters on the logistics costs of the service process of Scenario 1.

Based on all outcomes, we will conclude this thesis by providing several recommendations for both Philips and future research.

## 2.5 Scope

To secure that the research can be conducted within the prescribed six months, several scoping decisions are made, which are described below.

### 2.5.1 EMEA 2015

In Chapter 2.3 we explained that SPS distinguishes three global regions. Since these global regions greatly vary on their service process, this research is scoped on the single global region EMEA. It is assumed that one year covers enough orderlines to create a valid representation of the demand of spare parts. Therefore, we will only include data of the year 2015, containing ██████████ spare part orderlines.

### 2.5.2 PUDO Countries

In Chapter 4 it will be explained that in Scenario 1 the car stocks of FSEs will be replenished using so-called Pick-Up Drop-Off points (PUDOs). The research thus will be scoped to the countries in EMEA that contain these PUDOs, which are: Belgium, France, Germany, Ireland, The Netherlands, Portugal, Spain, and the United Kingdom. These countries account for ██████████ orderlines (62,2%) of the EMEA 2015 orderlines.

### 2.5.3 Corrective Maintenance Orders Requiring Spare Parts

At an unexpected failure of a part, corrective maintenance has to be performed. Since this maintenance is unplanned, it accounts for the highest logistics costs of the total service process. Therefore, it is decided to use defined car stocks only for this maintenance type. Since the introduction of car stocks only influences maintenance orders that require spare parts, we scope our research on corrective maintenance orders that require a spare part. We will elaborate on

these maintenance types in Chapter 3. As shown in Appendix A, the main part of outbound spare part orders is for corrective maintenance. Due to this scoping decision, █████ of the remaining orderlines are excluded, which leaves █████ orderlines (54,9%) of the EMEA 2015 orderlines.

#### 2.5.4 PUDO-Eligible SKUs

In Chapter 3 we explain that a SKU is PUDO-eligible if it weighs at most 25 kg, and in Chapter 6 we elaborate on the assumption that each SKU has a fixed order quantity for each SKU. Since in Scenario 1 car stocks will be replenished using PUDOs, we only include SKUs of which the total weight of the fixed order quantity is eligible to be send to a PUDO. Appendix B shows both the total number of unique SKUs and unique PUDO-eligible SKUs per modality demanded in 2015. This scoping decision excludes █████ of the remaining orderlines, and thus leaves █████ (50,9%) of the EMEA 2015 orderlines.

#### 2.5.5 Single-Location Distribution Network

In Chapter 3 we will explain that besides the RDC, SPS also makes use of Local Distribution Centres (LDCs) and Forward Stocking Locations (FSLs), to secure promised service levels in specific areas. Since 96,4% of the remaining orderlines is delivered via the RDC, and the setup of the spare parts distribution network for the LDC and FSL orderlines quite differ, it is decided to exclude these orderlines. We will further elaborate on these orders and corresponding part flow in Chapter 3. Due to this scoping, █████ of the remaining orderlines are excluded, and thus █████ orderlines (49,1%) of the EMEA 2015 orderlines remain.





## 3 Current Service Process (Scenario 0)

---

In this chapter, we describe the total current service process. First, we describe the different service contracts of all modalities and the different service calls from customers. Furthermore, the service process of FSEs and the spare parts distribution network are described.

### 3.1 Service Contracts

Philips distinguishes six main product modalities: Computed Tomography (CT), Diagnostic X-Ray Radiogrammetry (DXR), Image Guided Therapy (iXR), Magnetic Resonance Imaging (MR), Patient Care & Monitoring Solutions (PCMS), and Ultrasound (US). Together with all machines in these modalities, service contracts are sold. These contracts secure an agreed response time at failure of a machine and uptime of the machine.

Philips signs customer-specific service contracts with every customer. All contracts are based on one out of five general contract categories: *Support*, *Value*, *Select*, *Primary*, or *Uptime*. These categories are ranked from the lowest service levels (and thus least expensive service contract) to the highest service levels.

Each service contract contains three main agreements: initial response time, arrival time of FSEs, and uptime of the machine.

The initial response time is the time between the customer call for service and the first response (via mail or phone) from Philips. For the contract categories *Support*, *Value*, *Select*, and *Primary* this time varies between two and four hours. For the contract category *Uptime* this response time varies between one and two hours.

The arrival time of FSEs indicates the time between the customer call for service and first arrival of an FSE. For the contract categories *Support*, *Value*, *Select*, and *Primary*, this arrival time is agreed to be within one business day. The contract category *Uptime* assures an FSE arrival time between four and six hours.

The agreed uptime assures a percentage of time that the machine is working. For the contract categories *Support*, *Value*, *Select*, and *Primary*, the agreed uptime varies between 95% and 96%, whereas the agreed uptimes of the contract category *Uptime* varies between 97% and 98%

Philips thus does not have specific agreements about the time within which a spare part has to be delivered at the customer site, but instead has the combination of agreed uptime and the first visit of an FSE.

### 3.2 Service Calls

Philips distinguishes three types of service calls: *No Engineer Material Orders* (NEMO), *Preventive Maintenance* (PM), and *Corrective Maintenance* (CM). For each type of service call, the SPS department is responsible for the delivery of the needed spare parts.

NEMO orders are orders for one or more spare parts, without the request for an FSE. Some customers maintain their own machines, so at failure of a part, they detect, order and replace the failed part themselves.

To assure the agreed uptime levels of machines, Philips plans maintenance to prevent possible failures of parts, so-called *preventive maintenance*. Since it is planned which maintenance will be performed at which time, FSEs can already be scheduled and SPS can already plan the distribution of the possibly needed spare part beforehand.

At the unexpected failure of a machine, so-called *corrective maintenance* is performed. Philips first tries to solve the issue remotely via mail or phone. If this is not possible, an FSE will be sent to the customer site to detect the problem. If the needed maintenance does not require a spare part, the FSE fixes the problem immediately. Otherwise, the FSE orders the required spare part and, in general, installs the spare parts the next business day. Since corrective maintenance is unplanned, prescheduling of FSEs or planning of the spare part(s) distribution is not possible. The SPS department is only involved in corrective maintenance service calls if a spare part is requested. As discussed in Section 2.5, this research is scoped on these specific service calls.

SPS distinguishes *orderlines* and *orders*: an orderline consists of a demand of a specified order quantity for a specific Stock Keeping Unit (SKU), and an order consists of one or more orderlines. Appendix C shows both the number of orderlines per country and modality, and the number of orderlines per country and modality per FSE for this maintenance type. Furthermore, Appendix D shows the summed orderlines for each modality and the summed orderlines for each modality per FSE.

To gain insight into the car stock suitability per modality, we plotted the average part value against the average part size and the number of different SKUs per modality in Appendix E. Low part values will cause lower car stock inventory holding costs and low part sizes makes it possible to place many SKUs in the car stock. The modalities PCMS and DXR account for the lowest average part value and average part size, which is in favor of their car stock suitability. The modality MR has the highest average part value and average part size. Furthermore, the modality PCMS clearly shows the lowest number of unique SKUs demanded, which makes it possible to store a higher percentage of the total number of unique SKUs in the car stock. The modality DXR shows the highest variety of demanded SKUs.

### 3.3 FSEs

As explained in the previous section, FSEs are required for preventive and corrective maintenance service calls.

At preventive maintenance, an FSE visits the customer site to perform the scheduled maintenance. The distribution of possibly needed spare parts is planned beforehand, which ensures that at preventive maintenance an FSE only has to visit the customer site once. Spare parts were usually sent directly to the customer site by SPS. However, since FSEs are operational in dozens of hospitals and hospitals often do not have fixed pick-up points, SPS introduced Pick-Up Drop-Off (PUDO) locations in Europe, and currently has approximately 350 of these locations operational. PUDOs are for example supermarkets or gas stations. The regional RDC sends the ordered spare parts to the PUDO, so the FSE can pick it up and install the spare part at the customer. At the delivery of a spare part to either the customer site or PUDO, the FSE spends on average the same amount of time. However, FSEs commonly prefer spare part deliveries to PUDOs.

In case of corrective maintenance, an FSE visits the customer site to detect the problem. If no spare part is needed for the maintenance, the FSE fixes the problem immediately, and thus only needs one customer site visit. If the maintenance requires a spare part, the FSE orders it immediately. Except from emergency deliveries, a spare part usually is delivered within the next business day. If the spare part is delivered to a PUDO, the FSE picks up the part and drives to the customer site. If the spare part is sent to the customer site, the FSE directly drives to the customer site and collects the part. This second visit to the customer site thus always has a longer duration than the first visit, due to the time spend at collecting the spare part at either the PUDO or the customer site. In case of corrective maintenance where a spare part is needed, an FSE thus always visits a customer site twice.

Currently, spare parts are thus only sent to an FSE if specifically demanded for a service call. Besides several tool boxes, FSEs do not store anything in their car, and therefore drive in a normal sized family car, which they lease from Philips. SPS pays a fixed hourly cost rate per FSE, which includes the salary of the FSE but also all car-related costs as fuel, insurance, and depreciation.

Appendix F shows both the number of full-time FSEs per country and product modality and total number of FSE hours spend in 2015, split per activity type. The majority of the time, an FSE is busy with travelling, detecting defective machines, and performing maintenance. Besides these main tasks, the FSE has several tasks not directly related to failure of machines, for example job training or project meetings. It is assumed that currently FSEs on average are assigned tasks for 90% of the full time hours as stated in their contract.

### **3.4 Spare Part Distribution**

In case of the demand of a spare part, SPS is responsible for delivering the right part on the right place and time for the right cost. The current spare part distribution can be split into four flows: inbound, in-network, outbound, and reverse spare part flow.

#### **3.4.1 Inbound Flow**

Inbound flow is defined as the flow of parts towards one of the RDCs. The RDCs in AMEC, EMEA, and APAC are located in respectively Louisville, Roermond, and Singapore. SPS stores the stock per global region in the corresponding RDC. The SPS network consists of three types of inbound flows: new parts from internal suppliers, new parts from external suppliers, and repaired items from repair vendors. Approximately 70% of all new spare parts are sourced by an internal supplier, called a Business Innovation Unit (BIU). BIUs are located all around the world and deliver both single parts and assemblies. The rest of the new spare parts are ordered at external suppliers.

SPS pays a fixed amount of inbound handling costs per orderline. Consolidated inbound orders thus do not have any effect on these handling costs.

#### **3.4.2 In-Network Flow**

Besides the RDCs, SPS also makes use of Local Distribution Centres (LDCs) and Forward Stocking Locations (FSLs), to secure promised service levels in specific areas. Both LDCs and

FSLs are only replenished by the regional RDC, which is defined as the in-network flow. These replenishments are delivered by UPS economy service, which delivers the spare parts within three business days. No lateral transshipments are made between the storage locations.

The main function of LDCs is to make a next business day delivery possible. For example, SPS makes use of an LDC in Coventry to make these kind of deliveries possible in England. LDCs fulfil approximately a hundred time less orders than RDCs, and thus are also much smaller warehouses.

FSLs store only dozens of spare parts and are the smallest storage locations in the network of SPS. The FSLs are used to supply critical spare parts to specific customers within several hours to secure high uptime levels.

SPS pays a fixed amount of outbound handling costs at the RDC per orderline. SPS does not pay a fixed amount for in- and outbound handling at the LDCs and FSLs, but instead pays a fixed monthly fee for the use of each warehouse. Annual holding costs per part at one of the warehouses are within the SPS department assumed to be 20% of the value of the part. The main elements of these costs are the carrying costs of capital and the obsolescence costs.

### 3.4.3 Outbound Flow

Two types of outbound orders can be distinguished: next business day and emergency delivery. The majority of the outbound orders (~98,5%) are delivered by UPS express service, which delivers the spare parts the business day after ordering. The other outbound orders are delivered by taxi from one of the warehouses, which is the emergency delivery. At the RDCs and LDCs both types of delivery services are used. Spare parts from the FSLs are only delivered by taxi service.

Outbound orders are delivered either to a Key Market (KM), PUDO, or the customer site. A KM is a market that handles its own distribution, so SPS is only responsible for the delivery of spare parts to one fixed location in that market. Non-KM outbound orders are, if possible in terms of size and weight, preferably delivered to one of the PUDO locations. The rule of thumb used within SPS is that an orderline has to weigh at most 25 kg to be eligible to be sent to a PUDO. Since it is not always known beforehand which FSE will perform the maintenance, PUDO deliveries are sent to the PUDO which is the closest to the customer site. If PUDO delivery is not possible, outbound orders are sent directly to the customer site.

Again, SPS pays per orderline a fixed amount of outbound handling costs at the RDC and furthermore pays a fixed UPS transportation costs, based on chargeable weight and delivery country. PUDO handling costs are also paid per orderline, which includes both the in- and outbound handling.

### 3.4.4 Reverse Flow

SPS manages both consumable and repairable spare parts. Consumable spare parts are scrapped after failure, whereas repairables are sent back to a repair vendor to be repaired and used again. In EMEA, defective, repairable spare parts are sent back from the customer site to the In-Country Consolidation Point (ICCP) and in AMEC and APAC they are sent from the customer site to a Blue Room (BR). Every new or repaired spare part has a seal to detect whether the

package has been opened. If the seal of a spare part is not broken, it is directly sent from the ICCP to the RDC. If the seal is broken, it is sent to the BR where it will be inspected. If the BR detects that the spare part is not defective, it is sent to the RDC. Otherwise, it is sent to the repair vendor to repair it. After repair, it is sent to the RDC.

The described spare parts flow of the network layout is illustrated in Figure 3.

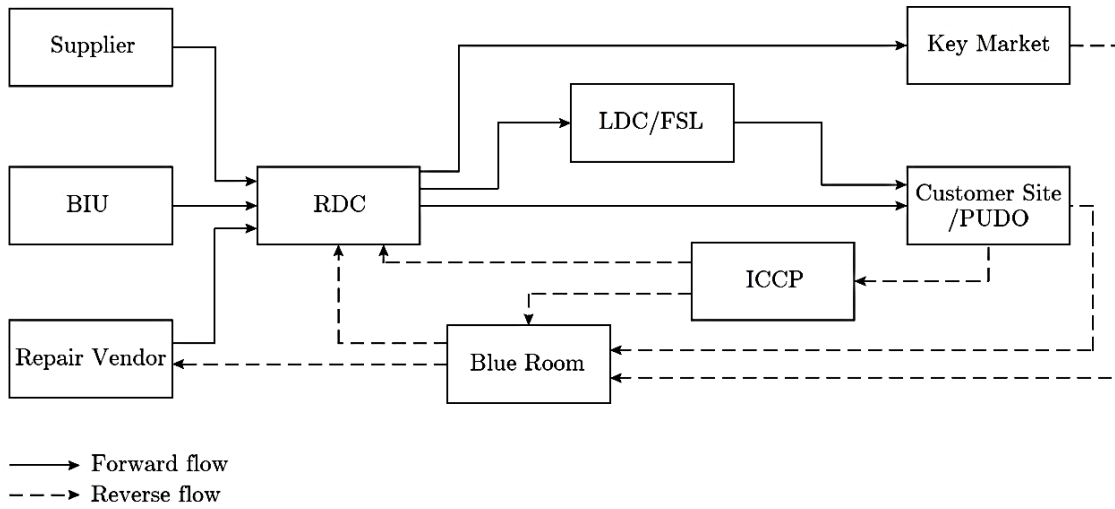


Figure 3: Current spare parts flow



## 4 Service Process with Car Stocks (Scenario 1)

---

In this chapter, we describe the proposed service process with car stocks. Since the type of service contracts and service calls remain unchanged, only the FSEs process and spare parts distribution of service process of Scenario 1 will be discussed.

### 4.1 FSEs

A predefined set of car stock spare parts will be assigned to each FSE, based on the modality and country the FSE is operating in. In case of a corrective maintenance call, the FSE visits the customer site to detect the cause of the failure. If the needed maintenance requires a specific spare part, and that part is available in the car stock, then the FSE will install the spare part immediately. The FSE immediately orders a new spare part for the car stock. If the defective part is not available in the car stock, then the FSE will follow the service process from Scenario 0, and thus will order the needed spare part and will install the part the next business day. The availability of the demanded spare part in the car stock thus decides whether an FSE will need one or two customer site visits. Since preventive maintenance and corrective maintenance orders that do not require a spare part are excluded from the scope of this research, the service process of these orders is assumed to remain unchanged in Scenario 1.

The car stocks of FSEs will be replenished using PUDOs, since these locations are not customer related. This requires all car stock orderlines to be eligible for PUDO handling, and thus be at most 25 kg. At each replenishment of the car stock, an FSE thus has to make an extra PUDO visit, which is not order related. To reduce the travel costs of these car stock replenishments, the replenishment order will be sent to the PUDO which is the closest to the FSE home address. This is possible, since car stock replenishments are always FSE specific.

FSEs now have to store both their toolboxes and the set of car stock spare parts, which requires bigger cars compared to Scenario 0. Since the FSE hourly costs not only include the salary of the FSE but also all car-related costs, this causes higher FSE hourly travel costs due to for example increase in fuel, insurance, and depreciation costs of the FSEs car.

Due to the possible savings of FSE travel hours in Scenario 1, it could be possible that less FSEs will be needed compared to Scenario 0. However, the number of FSEs per country and modality is limited by below. The introduction of car stocks only affects the FSE travelling hours for in-scope corrective maintenance orders, which on average accounts for 21,0% of the overall FSE hours, as shown in Appendix F. Furthermore, in the optimal scenario that all in-scope corrective maintenance orders can be fulfilled out of the car stock with a minimum number of car stock replenishments, FSE still needs to visit the customer site once for each of these orders. The sum of FSE hours that will remain unchanged in Scenario 1 compared to Scenario 0 and the minimum number of FSE travel hours spend on the in-scope corrective maintenance orders thus creates a lower limit for the number of FSEs needed per country and modality.

Again, we assume that FSEs on average will be assigned tasks for 90% of the full time hours as stated in their contract.

## 4.2 Spare Part Distribution

In the new service process with car stocks, the inbound, in-network, and reverse flow of spare parts will remain unchanged. Therefore, in this section we only describe the outbound flow of Scenario 1.

Three types of outbound orders will be distinguished: car stock replenishments, next business day, and emergency orders.

As described in the previous section, car stocks are replenished via PUDOs. To prevent many extra PUDO visits of FSEs, car stock replenishment orders will be delivered using a replenishment cycle with a fixed length. These replenishment orders will be delivered by the UPS economy service, which is less expensive than the UPS express service, to decrease overall spare part outbound transportation costs. The UPS economy service delivers the spare parts three business days after ordering.

If at demand a spare part is not available at the car stock, then the service process of Scenario 0 will be applied, and the FSE will thus order the spare part from the RDC using the express transportation mode. Again, all parts are preferably delivered to a PUDO and will otherwise be sent to the customer site.

As described in Chapter 2, emergency orders are out of the scope of this research, and therefore their outbound distribution will remain unchanged in Scenario 1. Furthermore, the fixed outbound handling costs at the RDC and PUDOs, and the inventory holding cost rate are assumed to remain unchanged.



# 5 Differences Current and Car Stock Scenario

This chapter concludes the qualitative part of this thesis, by outlining the differences between the described service process of Scenario 0 and Scenario 1, and furthermore defining the main cost buckets that change the logistics costs at the introduction of car stocks. Based on the described service processes in Chapter 3 and Chapter 4, four cost categories can be defined: spare part transportation, handling, FSE, and inventory holding costs.

## 5.1 Spare Part Transportation Costs

As described in Chapter 4, the inbound, in-network, and reverse flow of spare parts in Scenario 0 and Scenario 1 are similar. Furthermore, the preventive maintenance and emergency orders outbound process also remain unchanged. Only outbound spare part transportation costs of the scoped corrective maintenance orders will thus change in Scenario 1 compared to Scenario 0, and is therefore defined as the first main cost bucket.

In Scenario 0, all outbound spare part transportation of corrective maintenance orders within the scope of this research are delivered next business day using the UPS express transportation mode. In Scenario 1, these orders are split into car stock replenishments (using the UPS economy transportation mode) and next business day deliveries (using the UPS express transportation mode). The percentual difference between these two transportation modes in terms of costs are illustrated in Figure 4:

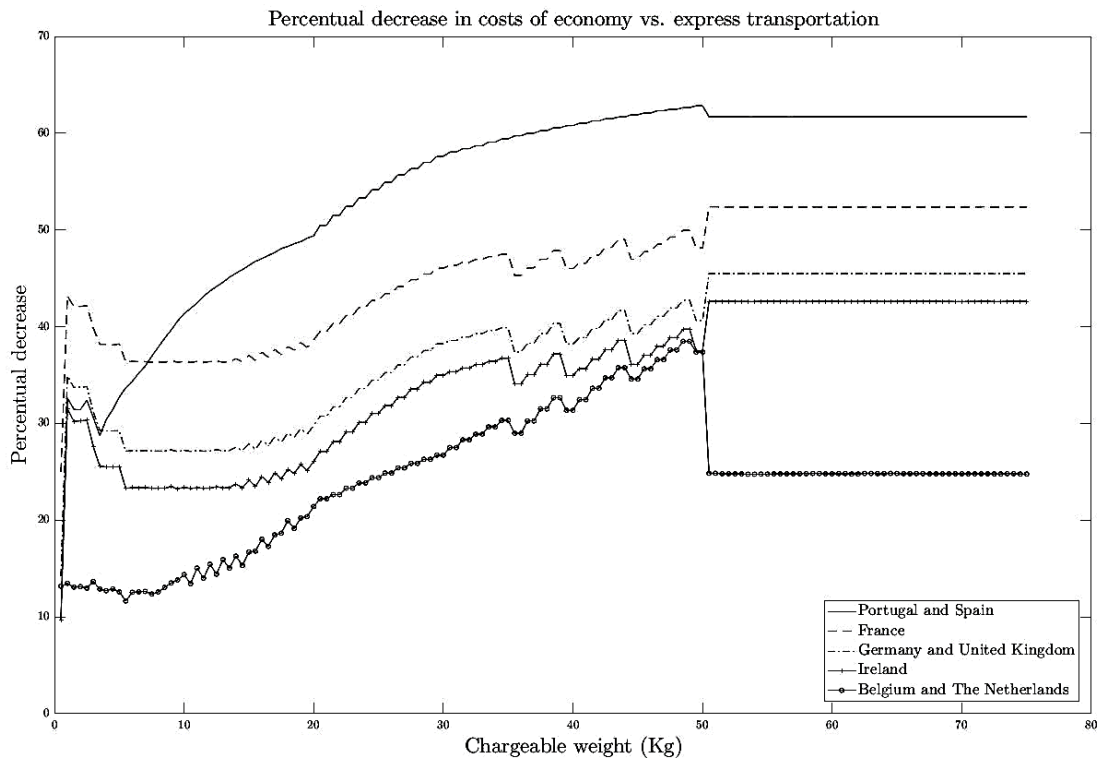


Figure 4: Percentual decrease in costs of economy vs. express transportation

Since for each chargeable weight of a part the economy transportation costs are lower than the express transportation costs, this cost bucket will decrease at the introduction of car stocks.

## 5.2 Handling Costs

The number of spare part orders at the RDC will not change at the introduction of car stocks, so the in- and outbound handling costs will remain unchanged. It is important to remind that both in- and outbound handling at the RDC are paid per orderline, so consolidated car stock replenishments will not have any effect on these handling costs.

Since car stocks will be replenished via PUDOs, less orders will be sent directly to the customer sites in Scenario 1, causing an increase in PUDO handling costs. PUDO handling costs are thus defined as the second main cost bucket.

## 5.3 FSE Costs

In both Scenario 0 and Scenario 1, FSEs has to perform the same detection and maintenance activities at the customer as in the current situation. The FSE costs do however change in three ways in Scenario 1 compared to Scenario 0.

In Scenario 0, in case of corrective maintenance that requires a spare part, an FSE always has to visit the customer site twice and has to collect the ordered spare part at either a PUDO or at the customer site. In Scenario 1, at the availability of the demanded part in the car stock, the FSE can directly perform the maintenance and thus saves both a second visit to the customer site and the time for collecting the ordered spare part at a PUDO or the customer site.

Second, due to the introduction of car stock replenishments, FSEs will have non-order related PUDO visits in Scenario 1, causing an increase in the FSE travel hours in Scenario 1 compared to Scenario 0.

Last, in Scenario 1 FSEs will need bigger cars to store their car stock inventory, causing an increase in the hourly travel rate of FSEs. This will affect the travel costs of all orders, both preventive and corrective maintenance.

The third main cost bucket is thus defined as the FSE costs.

## 5.4 Inventory Holding Costs

Within the scope of this research, two types of inventory locations are defined: the RDC and the cars of FSEs. Although the stock of the car stock parts will be decentralized at the introduction of car stocks, the amount of orders to be delivered from the RDC will remain unchanged. It is thus assumed that the slight change of stock levels at the RDC will have no significant influence on the logistics costs at the introduction of car stocks.

The car stock inventory holding costs are of course a new type of cost in Scenario 1 compared to Scenario 0. Therefore, car stock inventory holding costs are defined as the fourth main cost bucket, and will obviously increase if car stocks are introduced.

## 5.5 Conclusion

From this chapter we can conclude that the change in logistics costs in Scenario 1 compared to Scenario 0 is caused by four main cost buckets: outbound spare part transportation costs, PUDO handling costs, FSE costs, and car stock inventory holding costs. The trade-off decision to introduce car stocks will be decided by the increase in PUDO handling costs, FSE PUDO visits, the FSE hourly travel rate, and car stock inventory holding costs and the decrease in outbound transportation costs, FSE customer visits, and order-related collection of spare parts.



## 6 Cost and Optimization Model

---

In this chapter, we describe a cost model that determines the costs of the defined main cost buckets for Scenario 1 for a specific country and modality. We will explain that Scenario 0 is a special case of Scenario 1, which makes the model applicable for both scenarios. Furthermore, the main assumptions of the cost model are discussed and the behavior of SKUs in the car stock is evaluated. Then, we develop an optimization model and corresponding optimization algorithm that determines close-to-optimal basestock levels to minimize the total logistics costs per country and modality. To assure that efficient solutions can be generated by the optimization algorithm, we will prove that the objective function of the optimization problem is convex.

The optimization algorithm contains a greedy approach, which is based on the multi-item, single-location inventory model with emergency shipments of Chapter 2.9 from Van Houtum and Kranenburg (2016). As described in Chapter 4, if in Scenario 1 a spare part is demanded that is not available in the car stock, the service process from Scenario 0 is used instead of backordering the demand. In Scenario 1, this can thus be compared to the emergency option from the multi-item, single-location inventory model of Chapter 2.9 from Van Houtum and Kranenburg (2016). Demand fulfilled from the car stock can be compared to the non-emergency option.

A list of all denoted variables in this chapter is given in Appendix G.

### 6.1 Introduction

We consider a set of SKUs for a given modality and country, denoted by  $I = \{1, 2, \dots, |I|\}$ , with single SKU  $i \in I$ . It is assumed that the demand per SKU  $i$  occurs according to a Poisson process with a constant rate  $M_i (\geq 0)$ . Furthermore, as mentioned in Chapter 2, we assume that each SKU has a fixed order quantity.

The total number of operating full-time FSEs in Scenario 1 is denoted by  $f$ . It is assumed that for each country and modality, the demands per FSE are independent and identically distributed, implying that each demand is assigned to an FSE with probability  $q = \frac{1}{f}$ . Thus, the average annual demand per SKU  $i$  per FSE also occurs according to Poisson process (Adan & Resing, 2015), with a constant rate  $m_i = q \cdot M_i = \frac{M_i}{f}$ .

We will consider a basestock policy for the car stock of an FSE, with basestock level  $S_i (\geq 0)$  for each SKU  $i$ , which will be similar for each FSE in a specific country and modality. Let  $\beta_i(S_i)$  denote the (item) fill rate of SKU  $i$ , which is the probability that a part is available in the car stock at demand, given its basestock level  $S_i$ .

### 6.2 Cost Formulas

In Chapter 5 we concluded that the change in logistics costs in Scenario 1 compared to Scenario 0 is caused by four main cost buckets: outbound spare part transportation costs, PUDO

handling costs, FSE costs, and car stock inventory holding costs. In this section, we provide a cost formula that determines the total costs per cost bucket for both Scenario 0 and Scenario 1 for a given country and modality.

### 6.2.1 Outbound Transportation Costs

As explained in Chapter 4, in Scenario 1 car stocks are replenished via PUDOs using fixed replenishment cycles. Each replenishment cycle consists of a review and transportation period, as visualized in Figure 5. The FSE places a replenishment order after each review period, consisting of the demand during this review period. The replenishment order is delivered at the end of the transportation period.

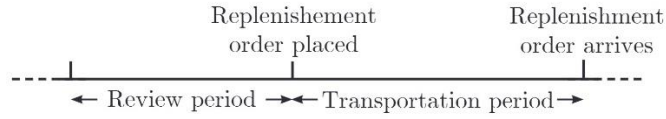


Figure 5: Car stock replenishment cycle

Let  $r$  denote the length of the review period in business days, and let  $t^{ec}$  denote the length of the transportation period in business days, which is equal to the leadtime of three business days of the UPS economy transportation mode. In practice, FSEs will thus apply periodic review of their car stock. However, to implement the inventory model of Chapter 2.9 from Van Houtum and Kranenburg (2016), we will approximate this periodic review by continuous review.

The maximum leadtime for a car stock SKU occurs when the demand of the SKU falls directly at the beginning of the review period, and equals the length of the complete replenishment cycle. If the demand for a car stock SKU falls exactly at the end of the review period, then the total SKU leadtime only equals the length of the transportation period. Thus, the mean leadtime of a car stock SKU order,  $t^{car}$ , is calculated by

$$\begin{aligned}
 t^{car} &= \frac{\sum_{i=0}^r [r - i + t^{ec}]}{r + 1} \\
 &= \frac{(r + 1) \cdot (r + t^{ec}) - \sum_{i=0}^r i}{r + 1} \\
 &= r + t^{ec} - \frac{r(r + 1)}{2(r + 1)} \\
 &= \frac{1}{2}r + t^{ec}
 \end{aligned}$$

If a spare part is not available in the car stock at demand, the service process of Scenario 0 is applied and the spare part is thus ordered at the RDC using the UPS express transportation mode. This mode has an agreed leadtime, denoted by  $t^{ex}$ , of one business day.

As described in Chapter 3, outbound spare part transportation costs are paid per orderline and is dependent on the SKU, delivery country, and transportation mode. The outbound transportation costs for SKU  $i$  for economy and express transportation are denoted by  $c_i^{t,ec}$  and  $c_i^{t,ex}$  respectively. We can now formulate the outbound spare part transportation costs in

Scenario 1, under a given set of car basestock levels  $\mathbf{S}$ , car stock review period length of  $r$ , and number of full-time FSEs  $f$ , as:

$$C^T(\mathbf{S}, r, f) = f \cdot \sum_{i \in I} m_i \cdot [\beta_i(S_i) \cdot c_i^{t,ec} + (1 - \beta_i(S_i)) \cdot c_i^{t,ex}]$$

If in Scenario 1 no stock is placed in the car of the FSEs, the availability in the car stock for all SKUs is zero, and thus always the service process of Scenario 0 is applied. Therefore, Scenario 0 is a special case of Scenario 1, with the set of car basestock levels and review period length, given by  $\mathbf{S} = \mathbf{0}$  and  $r = 0$  respectively. Furthermore, we denote  $f^{cur}$  as the number of operating full-time FSEs in Scenario 0, as given in Appendix F. The outbound spare part transportation costs for Scenario 0 are thus given by:

$$\begin{aligned} C^T(\mathbf{0}, 0, f^{cur}) &= f^{cur} \cdot \sum_{i \in I} m_i \cdot [0 \cdot c_i^{t,ec} + 1 \cdot c_i^{t,ex}] \\ &= f^{cur} \cdot \sum_{i \in I} m_i \cdot c_i^{t,ex} \end{aligned}$$

### 6.2.2 PUDO Handling Costs

Because of the personal decision of the FSE in Scenario 0 to collect a part at a PUDO or at the customer site, it is not possible to explicitly define per part in which situation it is sent to a PUDO or not. Therefore we denote a probability  $p_i$  ( $0 \leq p_i \leq 1$ ) for each SKU  $i$ , which represents the chance that the SKU will be sent to a PUDO. These probabilities are estimated based on the scoped orderlines of 2015. As described in Chapter 3, SPS pays a fixed PUDO handling cost per orderline of ████ EUR, which we denote by  $c^p$ . The total PUDO handling costs in Scenario 1 can now, under a given set of car basestock levels  $\mathbf{S}$ , car stock review period length of  $r$ , and number of full-time FSEs  $f$ , be given by:

$$C^P(\mathbf{S}, r, f) = c^p \cdot f \cdot \sum_{i \in I} m_i \cdot [\beta_i(S_i) + (1 - \beta_i(S_i)) \cdot p_i]$$

For Scenario 0, the PUDO handling costs are thus given by:

$$\begin{aligned} C^P(\mathbf{0}, 0, f^{cur}) &= c^p \cdot f^{cur} \cdot \sum_{i \in I} m_i \cdot [0 + (1 - 0) \cdot p_i] \\ &= c^p \cdot f^{cur} \cdot \sum_{i \in I} m_i \cdot p_i \end{aligned}$$

### 6.2.3 FSE Costs

We denote  $h^{cust}$  as the average return travel time of an FSE to a customer site and  $h^{coll}$  as the average time an FSE spends on collecting a spare part at either a PUDO or the customer site. As explained in Chapter 3, the time an FSE spends on collecting a spare part at either a PUDO or at the customer site is assumed to be the same. In Appendix H the average return travel times to a customer site and the average spare part collecting time in 2015 are given per country.

Let  $h^{repl}$  denote the car stock replenishment collecting time at a PUDO. In Chapter 4 we explained that in Scenario 1, car stock replenishment orders will be sent to the PUDO which is the closest to the FSEs home address. Furthermore, since FSEs travel to a customer site every day, in practice they do not need a return travel to this PUDO, but can visit the PUDO on their way to a customer site. Therefore, we assume that the average collecting time of a car stock replenishment at a PUDO equals twice the average time an FSE spends on collecting a spare part in Scenario 0, thus  $h^{repl} = 2 \cdot h^{coll}$ .

As explained in Chapter 4, we assume that the hourly FSE travel cost rate increases in Scenario 1 compared to Scenario 0. We denote  $V^{car}$  as the maximum effective storage capacity in  $m^3$  of an FSE car,  $c^f$  as the hourly FSE cost rate in EUR in Scenario 0, and  $c^{trav}$  as the hourly FSE travel cost rate in Scenario 1. We assume that this travel cost rate linearly increases on the storing capacity of the car:

$$c^{trav} = c^f \cdot (1 + 0,025 \cdot V^{car})$$

Since this new travel cost rate will also influences the total travel costs of the maintenance orders outside the scope of this research in Scenario 1, we denote  $H^{trav}$  as the total FSE travel hours on these out-of-scope orders per country and modality. In Appendix H, the average observed FSE travel hours on these out-of-scope orders are given per country and modality in 2015. We assume that the hourly FSE costs for non-travelling and spare parts collecting activities will remain unchanged in Scenario 1 compared to Scenario 0.

Furthermore, we denote  $w^f$  as the total working days per FSE per year. As described in Chapter 3, we assume that currently FSEs on average are assigned tasks for 90% of the full time hours as stated in their contract. Based on the FSE hours as stated in Appendix F, we assume that an FSE is contracted for 227 days per year and 8 hours per day. The total yearly replenishments per FSE can thus be found by dividing the total yearly working days per FSE by the chosen review period length.

We can now formulate the FSE costs in Scenario 1, given the set of basestock levels  $\mathbf{S}$ , car stock review period length of  $r$ , and number of full-time FSEs  $f$ , as the sum of FSE travel costs on in-scope orders, FSE travel costs on out-of-scope orders, and FSE collecting costs of car stock replenishments:

$$\begin{aligned} C^F(\mathbf{S}, r, f) &= f \cdot \sum_{i \in I} m_i \cdot [\beta_i(S_i) \cdot h^{cust} \cdot c^{trav} + (1 - \beta_i(S_i)) \cdot (2h^{cust} \cdot c^{trav} + h^{coll} \cdot c^f)] \\ &\quad + H^{trav} \cdot c^{trav} + f \cdot \frac{w^f}{r} \cdot h^{repl} \cdot c^f \end{aligned}$$

In Scenario 0 it holds that  $c^{trav} = c^f$ , thus the FSE costs for Scenario 0 are then given by:

$$\begin{aligned} C^F(\mathbf{0}, 0, f^{cur}) &= (2h^{cust} \cdot c^f + h^{coll} \cdot c^f) \cdot f^{cur} \cdot \sum_{i \in I} [m_i] + H^{trav} \cdot c^f + f^{cur} \cdot \frac{w^f}{0} \cdot h^{repl} \cdot c^f \\ &= c^f \cdot (2h^{cust} + h^{coll}) \cdot f^{cur} \cdot \sum_{i \in I} [m_i] + c^f \cdot H^{trav} \end{aligned}$$



### 6.2.4 Car Stock Inventory Holding Costs

As mentioned in Chapter 3, annual holding costs per part, denoted by  $c^h$ , are within the SPS department assumed to be 20% of the value of the part. We denote  $OH_i(S_i)$  as the expected on-hand inventory level of SKU  $i$ , given its basestock level  $S_i$ . Furthermore, let  $c_i$  denote the value of SKU  $i$  in EUR. Under a given set of car basestock levels  $\mathbf{S}$ , car stock review period length of  $r$ , and number of full-time FSEs  $f$ , the total car stock inventory holding costs in Scenario 1 are given by:

$$C^H(\mathbf{S}, r, f) = f \cdot c^h \cdot \sum_{i \in I} OH_i(S_i) \cdot c_i$$

In Scenario 0, the car stock inventory holding costs are clearly equal to zero.

### 6.2.5 Conclusion

The overall cost model is thus represented by the sum of all costs of the defined cost buckets. Under a given set of car basestock levels  $\mathbf{S}$ , car stock review period length of  $r$ , and number of full-time FSEs  $f$ , the logistics costs for Scenario 1 per country and modality are thus given by:

$$C(\mathbf{S}, r, f) = C^T(\mathbf{S}, r, f) + C^F(\mathbf{S}, r, f) + C^P(\mathbf{S}, r, f) + C^H(\mathbf{S}, r, f)$$

The logistics cost for Scenario 0 are defined as

$$C(\mathbf{0}, 0, f^{cur}) = C^T(\mathbf{0}, 0, f^{cur}) + C^F(\mathbf{0}, 0, f^{cur}) + C^P(\mathbf{0}, 0, f^{cur}) + C^H(\mathbf{0}, 0, f^{cur})$$

## 6.3 Assumptions

The main assumptions of the cost model are discussed below:

*1. Demand for the different SKUs occur according to independent Poisson processes with a constant demand rate*

This assumption has been tested by Huyps (2015) by conducting a generic Chi-squared test on several SKUs of SPS to compare four years of historical monthly demand with a generated set of Poisson distributed monthly demand. It was concluded that this assumption does not need to be rejected. Since both downtimes of machines are short and occur rarely, the assumption of a constant demand rate is reasonable.

*2. For each country and modality, the demands per FSE are independent and identically distributed*

The number of FSEs per country and modality, as listed in Appendix F, only include fulltime FSEs. Furthermore, FSEs are (as far as possible) equally distributed over each country. Therefore it is reasonable to assume that the total demand of maintenance in each country and for each modality will be equally distributed among the number of FSEs per country and modality.

3. *Transport leadtimes for different SKUs are independent and transport leadtimes of the same SKU are independent and identically distributed*

Since the leadtimes of both economy and express deliveries from the RDC are agreed with UPS, this is reasonable to assume. Hereby it is also assumed that at demand, SKUs are always available at the RDC. For the majority of SKUs, Philips has set high fill rate levels which makes this assumption reasonable.

4. *A one-for-one replenishment strategy is applied for all SKUs*

Although the minority of orderlines consists of a single demand for a SKU, this assumption does not need to be rejected immediately. It is tested what the variability in order quantity per SKU is, of which the results are stored in Appendix I. Since approximately 83% of all SKUs have no variance in its order quantity, and only 4,7% of all SKUs have an order quantity of above 1, it is reasonable to assume that each SKU has a fixed order quantity. Thus, a one-for-one replenishment strategy with a fixed order quantity for all SKUs can be assumed. In the remainder of this thesis, each characteristic of a SKU (value, size, and weight) will thus be multiplied by this fixed order quantity to define the average characteristics for a demand of each SKU. One SKU in this thesis thus represents a set of the fixed order quantity of that SKU.

## 6.4 Evaluation Car Stock

In this section we evaluate the behavior of SKUs in the car stock of an FSE. Comparable to the multi-item single-location inventory model with emergency shipments of Chapter 2.9 from Van Houtum and Kranenburg (2016), we are interested in the item fill rate per SKU for a given basestock level. Furthermore, we analyze, given a set of car basestock levels, the behavior of the on-hand inventory per SKU in the car of the FSE.

We define the order pipeline  $X_i$  as the number of SKUs that are at a given moment in time in order for the car stock of an FSE. Since a basestock policy without backorders is considered, the number of SKUs in the order pipeline is bounded from above by  $S_i$  for each SKU  $i$ . This order pipeline thus behaves as a  $M/G/c/c$ -queue. This *Erlang loss system* is visualized in Figure 6.

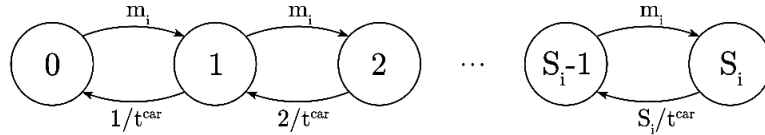


Figure 6: Flow diagram of the order pipeline stock  $X_i$

Adan and Resing (2015) show that:

$$P(X_i = x) = \frac{\rho_i^x / x!}{\sum_{y=0}^{S_i} \rho_i^y / y!}$$

with

$$\rho_i = \frac{m_i}{1/t^{car}} = m_i \cdot t^{car}$$

A demand for SKU  $i$  can not be fulfilled directly from the car stock if all  $S_i$  parts are in order, also referred to as the *blocking probability*. The (item) fill rate of SKU  $i$  is given by 1 minus this probability:

$$\begin{aligned} \beta_i(S_i) &= 1 - P(X_i = S_i) \\ &= 1 - \left( \frac{\rho_i^{S_i}/S_i!}{\sum_{y=0}^{S_i} \rho_i^y/y!} \right) \end{aligned}$$

Since the on-hand inventory level of a specific SKU is equal to its basestock level minus the number of SKUs that are in order, the average on-hand inventory level of SKU  $i$  is given by:

$$OH_i(S_i) = \sum_{x=0}^{S_i} P(X_i = x) \cdot (S_i - x)$$

## 6.5 Optimization Problem

To define the optimal set of basestock level for an FSE car for a specific country and modality, we formulate an overall optimization model in this section, which aims to minimize logistics costs of the defined cost buckets in Scenario 1. The decision variables of the model are the set of car basestock levels of all SKUs.

By setting the car basestock levels of all SKUs, the model is limited by the available storage capacity of the car, which has been defined as  $V^{car}$ . Let  $v_i$  denote the volume in  $m^3$  of SKU  $i$ . Under a given set of basestock levels, the maximum space occupied in  $m^3$  of the car of an FSE is then given by:

$$V(\mathbf{S}) = \sum_i S_i \cdot v_i$$

As defined in Chapter 6.2, the overall cost function has, besides the set of basestock levels, two other input parameters: the car stock review period length and the number of full-time FSEs.

We define the set of possible review period lengths by  $R \in \{1, 2, \dots, w^f\}$ . Thus, the review period can only be an integer number of business days and at least once per year the car stock has to be reviewed.

As described in Chapter 4, a lower limit for the number of FSEs needed is created by the sum of the total number of FSE hours that remain unchanged in Scenario 1 compared to Scenario 0 due to the research scope, and the minimum number of FSE travel hours spend on the in-scope corrective maintenance orders per country and modality. Let  $H^{other}$  denote the total number of out-of-scope FSE hours not spend on travelling. Appendix H shows the average observed FSE hours spend on these out-of-scope non-travelling activities per country and

modality in 2015. Now we can denote  $H^{out}$  as the total number of out-of-scope FSE hours, with  $H^{out} = H^{trav} + H^{other}$ . Furthermore, we denote the number of in-scope FSE travel hours by  $h(\mathbf{S}, r, f)$ , which can be derived from the FSE cost formula defined in Chapter 6.2.3:

$$h(\mathbf{S}, r, f) = f \cdot \sum_{i \in I} m_i \cdot [\beta_i(S_i) \cdot h^{cust} + (1 - \beta_i(S_i)) \cdot (2h^{cust} + h^{coll})] + f \cdot \frac{w^f}{r} \cdot h^{repl}$$

The minimum number of in-scope FSE travel hours can thus, given the number of full-time FSEs  $f$ , be found if all SKUs are always available in the car stock at demand ( $\beta_i(S_i) = 1$  for all  $i \in I$ ) and if the minimum number of annual car stock replenishments are made ( $r = w^f$ ). Let  $h^{full}$  denote the average yearly contract hours of an FSE. Since we assumed an 8-hours working day in Chapter 6.2.3.,  $h^{full} = w^f \cdot 8 = 1.816$  hours. Furthermore, we denote the minimum number of full-time FSEs needed by  $f^{\min}$ , which is defined as:

$$f^{\min} = \left\lceil \frac{H^{out} + h(\mathbf{S}, w^f, f)}{h^{full}} \right\rceil, \text{ with } \mathbf{S} \text{ such that } \boldsymbol{\beta}(\mathbf{S}) = \mathbf{1}$$

In Appendix J, the minimum number of needed full-time FSEs needed is listed per country and modality. We can now define the set of possible number of FSEs hired by  $F \in \{f^{\min}, f^{\min} + 1, \dots, f^{cur}\}$ .

The overall optimization problem for minimization of total logistics costs in Scenario 1 can thus be defined as:

$$\begin{aligned} \min \quad & C(\mathbf{S}, r, f) \\ \text{s. t.} \quad & V(\mathbf{S}) \leq V^{car} \\ & r \in R, f \in F \end{aligned}$$

## 6.6 Convexity of Objective Function

Before defining an optimization algorithm, it has to be proven that an optimal solution for the defined overall optimization problem can be found. Therefore, since  $V(S_i)$  is linearly increasing on its whole domain for every  $i \in I$ , we have to prove that the objective function is convex and thus has only one minimum.

By the definition of a convex function (Beckenbach, 1948), the function  $C(\mathbf{S}, r, f)$  is said to be convex if, for every  $i \in I$  and  $S_i \geq 1$ :

$$C(S_i + 1, r, f) - C(S_i, r, f) \geq C(S_i, r, f) - C(S_i - 1, r, f)$$

Since  $C(\mathbf{S}, r, f)$  is the sum the four cost functions of the defined cost buckets, and the sum of four convex functions is also convex (Beckenbach, 1948), we can prove the convexity of  $C(\mathbf{S}, r, f)$  by proving that each cost function of each cost buckets is convex.

Considering Remark 2 in Kranenburg and Van Houtum (2007), Karush (1957) has shown that the Erlang loss probability ( $P(X_i = x)$ ), is decreasing and strictly convex as a function of  $S_i$  for

every  $i \in I$ . This implies that the (item) fill rate of SKU  $i$  ( $\beta_i(S_i)$ ) is increasing and strictly concave on its whole domain.

The cost formula of the spare part outbound transportation costs for a single SKU  $i \in I$  is defined as:

$$C_i^T(S_i, r, f) = f \cdot m_i \cdot [\beta_i(S_i) \cdot c_i^{t,ec} + (1 - \beta_i(S_i)) \cdot c_i^{t,ex}]$$

Since  $f$  and  $m_i$  are strictly positive constants,  $c_i^{t,ex} > c_i^{t,ec}$  for each  $i \in I$ , and  $\beta_i(S_i)$  is increasing and strictly concave on its whole domain,  $C_i^T(S_i, r, f)$  is decreasing and strictly convex as a function of  $S_i$  for every  $i \in I$ .

As defined in Chapter 6.2, the cost formula of the FSE costs for a given set of basestock levels consist of the sum of FSE travel costs on in-scope orders, FSE travel costs on out-of-scope orders, and FSE collecting costs of car stock replenishments. Since these latter two components are independent of the set of basestock levels, the cost formula is convex if we can prove that the cost function of FSE travel costs on in-scope orders is convex for each  $i \in I$ , which is defined as:

$$c_i^F(S_i, f) = f \cdot m_i \cdot [\beta_i(S_i) \cdot h^{cust} \cdot c^{trav} + (1 - \beta_i(S_i)) \cdot (2h^{cust} \cdot c^{trav} + h^{coll} \cdot c^f)]$$

Since  $f$  and  $m_i$  are strictly positive constants,  $0 < h^{cust} \cdot c^{trav} < 2h^{cust} \cdot c^{trav} + h^{coll} \cdot c^f$ , and  $\beta_i(S_i)$  is increasing and strictly concave on its whole domain,  $c_i^F(S_i, f)$  is decreasing and strictly convex as a function of  $S_i$  for every  $i \in I$ . Thus, the cost formula of the FSE costs is also decreasing and strictly convex as a function of  $S_i$  for every  $i \in I$ .

The cost formula of the car stock inventory holdings costs for a single SKU  $i \in I$  is defined as:

$$C_i^H(S_i, r, f) = f \cdot c^h \cdot OH_i(S_i) \cdot c_i$$

Please remind that:

$$OH_i(S_i) = \sum_{x=0}^{S_i} P(X_i = x) \cdot (S_i - x)$$

Since the Erlang loss probability is decreasing and strictly convex as a function of  $S_i$  for every  $i \in I$ , the on-hand inventory is increasing and strictly convex on its whole domain. Furthermore, since  $f$ ,  $c^h$  and  $c_i$  are strictly positive constants,  $C_i^H(S_i, r, f)$  is also increasing and strictly convex as a function of  $S_i$  for every  $i \in I$ .

The costs formula of PUDO handling costs for a single SKU  $i \in I$  is defined as:

$$C_i^P(S_i, r, f) = c^p \cdot f \cdot m_i \cdot [\beta_i(S_i) + (1 - \beta_i(S_i)) \cdot p_i]$$

Since  $c^p$ ,  $f$ , and  $m_i$  are constants,  $0 \leq p_i \leq 1$ , and  $\beta_i(S_i)$  is increasing and strictly concave on its whole domain, it can be concluded that  $C_i^P(S_i, r, f)$  is increasing and strictly concave as a function of  $S_i$  for every  $i \in I$ . This however does not immediately mean that  $C(\mathbf{S}, r, f)$  is not

convex. It could be possible that the other three convex functions compensate the concavity of  $C_i^P(S_i, r, f)$ . We therefore check if the sum of  $C_i^F(S_i, r, f)$  and  $C_i^P(S_i, r, f)$  is convex, by:

$$\begin{aligned} & \{C_i^F(S_i + 1, r, f) + C_i^P(S_i + 1, r, f)\} - \{C_i^F(S_i, r, f) + C_i^P(S_i, r, f)\} \\ & \geq \{C_i^F(S_i, r, f) + C_i^P(S_i, r, f)\} - \{C_i^F(S_i - 1, r, f) + C_i^P(S_i - 1, r, f)\} \end{aligned}$$

With

$$\begin{aligned} C_i^F(S_i, r, f) &= f \cdot m_i \cdot [\beta_i(S_i) \cdot h^{cust} \cdot c^{trav} + (1 - \beta_i(S_i)) \cdot (2h^{cust} \cdot c^{trav} + h^{coll} \cdot c^f)] \\ & \quad + H^{trav} \cdot c^{trav} + f \cdot \frac{w^f}{r} \cdot h^{repl} \cdot c^f \end{aligned}$$

For simplicity, we define the constants  $x, y$ , and  $z$ , with  $x = h^{cust} \cdot c^{trav}$ ,  $y = h^{coll} \cdot c^f$ , and  $z = H^{trav} \cdot c^{trav} + f \cdot \frac{w^f}{r} \cdot h^{repl} \cdot c^f$ . This gives:

$$\begin{aligned} & C_i^F(S_i, r, f) + C_i^P(S_i, r, f) \\ & = f \cdot m_i \cdot [\beta_i(S_i) \cdot x + (1 - \beta_i(S_i)) \cdot (2x + y) + c^p \cdot \beta_i(S_i) + c^p \cdot p_i \cdot (1 - \beta_i(S_i))] + z \\ & = f \cdot m_i \cdot [\beta_i(S_i) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} + (2x + y) + c^p \cdot p_i] + z \end{aligned}$$

Thus, the sum of  $C_i^F(S_i, r, f)$  and  $C_i^P(S_i, r, f)$  is convex, if:

$$\begin{aligned} & \{f \cdot m_i \cdot [\beta_i(S_i + 1) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} + (2x + y) + c^p \cdot p_i] + z\} \\ & \quad - \{f \cdot m_i \cdot [\beta_i(S_i) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} + (2x + y) + c^p \cdot p_i] + z\} \\ & \geq \{f \cdot m_i \cdot [\beta_i(S_i) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} + (2x + y) + c^p \cdot p_i] + z\} \\ & \quad - \{f \cdot m_i \cdot [\beta_i(S_i - 1) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} + (2x + y) + c^p \cdot p_i] + z\} \end{aligned}$$

Since  $f \cdot m_i \geq 0$  for all  $i \in I$ :

$$\begin{aligned} & \beta_i(S_i + 1) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} - \beta_i(S_i) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} \\ & \geq \beta_i(S_i) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} - \beta_i(S_i - 1) \cdot \{x - (2x + y) + c^p - c^p \cdot p_i\} \end{aligned}$$

Because  $\beta_i(S_i)$  is increasing and strictly concave on its whole domain,  $\beta_i(S_i + 1) - \beta_i(S_i) < \beta_i(S_i) - \beta_i(S_i - 1)$ . Our equation thus only holds if:

$$\begin{aligned} & \{x - (2x + y) + c^p - c^p \cdot p_i\} < 0 \\ & -h^{cust} \cdot c^{trav} - h^{coll} \cdot c^f + c^p - c^p \cdot p_i < 0 \\ & (1 - p_i) \cdot c^p < h^{cust} \cdot c^{trav} + h^{coll} \cdot c^f \end{aligned}$$

Since  $0 \leq p_i \leq 1$  for all  $i \in I$  and, as defined in Chapter 6.2.2,  $c^p = \blacksquare$ , the left-hand side of this equation is at maximum equal to  $\blacksquare$ . From the minimum values of  $h^{cust}$  and  $h^{coll}$  in Appendix H, it can be concluded that this equation holds for every country.

Thus,  $C_i^F(S_i, r, f) + C_i^P(S_i, r, f)$ ,  $C_i^T(S_i, r, f)$ , and  $C_i^H(S_i, r, f)$  are all convex as a function of  $S_i$  for every  $i \in I$ , which proves that  $C(\mathbf{S}, r, f)$  is also a convex as a function of  $S_i$  for every  $i \in I$ . We can thus find an optimal solution for the overall optimization problem.

## 6.7 Optimization Algorithm

To approximate the optimal solution of the defined optimization problem, we propose an optimization algorithm that determines close-to-optimal car basestock levels and corresponding logistics costs for each possible set of car stock review period length and number of FSEs by using a greedy approach. The optimization algorithm is given in Table 1.

For each possible combination of car stock review period lengths and number of full-time FSEs, the algorithm repeatedly executes the first four steps.

In Step 1, the algorithm sets the car basestock levels for each SKU and the corresponding maximum occupied storage capacity of the car equal to zero. Furthermore, the total logistics costs for this set of basestock levels is calculated.

Then, in Step 2, the algorithm decides which SKU is the ‘most optimal’ to increase its basestock level by one. It therefore calculates the change in logistics costs for each SKU, if the basestock level of that SKU would be increased by one, and divides this by the volume of the SKU. For SKU  $i$ , this change in logistics costs is given by:

$$\Delta_i C(\mathbf{S}, r, f) := C(S_i + 1, r, f) - C(S_i, r, f)$$

By dividing this change in logistics costs by the volume of the SKU, the algorithm prevents that only a few high-volume SKUs with a high individual savings if their basestock level is increased will be placed in the car, whereas the sum in total logistics costs savings of a higher amount of low-volume SKUs that have a lower individual saving if their basestock level is increased. For example, consider a car storage capacity of 1 m<sup>3</sup>, one SKU with a volume of 1 m<sup>3</sup> and ten different SKUs with each a volume of 0,1 m<sup>3</sup>. Suppose that, if their basestock level is increased by one, the decrease in logistics costs for the single part is 1.000 EUR and 200 EUR each for the other SKUs. If the algorithm would only take the total savings in logistics costs into account, only the single SKU would be placed in the car stock, saving 1.000 EUR. By also taking the SKUs volumes into account, the algorithm chooses to increase the basestock levels of the ten smaller SKUs with total savings of 2.000 EUR.

When the algorithm decided which SKU is the most optimal one, it checks whether an increase of the basestock level of this SKU actually causes a decrease in total logistics costs. If this is not the case, the algorithm defines the current set of basestock levels as the most optimal set, denoted by  $\mathbf{S}_{r,f}^*$ , with corresponding costs, denoted by  $\theta_{r,f}$ , and continues in Step 4. Otherwise the basestock level of the most optimal SKU is increase by one, the maximum occupied storage capacity of the car is increased by the SKUs volume, and the total logistics costs are lowered by the found savings in logistics costs due to the increase of the basestock level of the defined SKU.

---

**Optimization Algorithm**


---

**Input**  $I, R, F, C(\mathbf{S}, r, f), v_i (\forall i \in I), V^{car}$

**Output**  $r^*, f^*, \mathbf{S}^*, C^*(\mathbf{S}, r, f)$

**Begin**

For each  $r \in R, f \in F$

Step 1

Set  $\mathbf{S} := 0, V(\mathbf{S}) := 0$ , calculate  $C(\mathbf{S}, r, f)$

Step 2

Calculate  $\Gamma_i = \frac{-\Delta_i C(\mathbf{S}, r, f)}{v_i}, \forall i \in I$

$k = \text{argmax}\{\Gamma_i: i \in I\}$

If  $\Delta_k C(\mathbf{S}, r, f) > 0$ , then  $\mathbf{S}_{r,f}^* = \mathbf{S}, \theta_{r,f} = C(\mathbf{S}, r, f)$ , go to Step 4.

Else,  $\mathbf{S} = \mathbf{S} + \mathbf{e}_k, V(\mathbf{S}) = V(\mathbf{S}) + v_k, C(\mathbf{S}, r, f) = C(\mathbf{S}, r, f) + \Delta_k C(\mathbf{S}, r, f)$

Step 3

If  $V(\mathbf{S}) > V^{car}$ , then  $\mathbf{S}_{r,f}^* = \mathbf{S} - \mathbf{e}_k, \theta_{r,f} = C(\mathbf{S}, r, f) - \Delta_k C(\mathbf{S}, r, f)$ , go to Step 4.

Else, go to Step 2.

Step 4

If  $f \cdot h^{full} < H^{out} + h(\mathbf{S}_{r,f}^*, r, f)$ , then  $\theta_{r,f} = \infty$ , stop.

Else, stop.

End

Step 5

$(r^*, f^*) = \text{argmin}\{\theta_{r,f}: r \in R, f \in F\}$

$\mathbf{S}^* = \mathbf{S}_{r^*, f^*}^*$

$C^*(\mathbf{S}, r, f) = C(\mathbf{S}^*, r^*, f^*)$

**End**

---

*Table 1: Optimization algorithm*

In Step 3, the algorithm checks if, due to the new set of basestock levels as defined in Step 2, the maximum occupied storage capacity of the car is exceeded. If this is the case, the basestock level that has just been increased is lowered by one, and the algorithm defines this new set of basestock levels as the most optimal set. It furthermore recalculates the corresponding total logistics costs.

Based on the defined optimal set of basestock levels, the algorithm checks in Step 4 if this set in combination with the review period length and number of full-time FSEs provides a feasible solution. The combination of basestock levels, review period length and number of full-time FSEs is only feasible if the total needed FSE hours (sum of out-of-scope FSE hours and in-scope FSE travelling hours) does not exceed the available FSE hours (number of FSEs multiplied by their working hours as stated in their contract). If this is not the case, the corresponding calculated logistics costs are set to infinite.



The algorithm now determined for each possible combination of car stock review period lengths and number of full-time FSEs the optimal set of basestock levels and corresponding total logistics costs. In Step 5, the algorithm sets the optimal set of review period length and number of FSEs, denoted by  $r^*$  and  $f^*$  respectively, that account for the lowest logistics costs. Lastly, it outputs the corresponding optimal set of basestock levels and logistics costs, denoted by  $\mathbf{S}^*$  and  $C^*(\mathbf{S}, r, f)$  respectively.



## 7 Implementation Optimization Algorithm

In this chapter we apply the optimization algorithm of Chapter 6 for each country and modality on the scoped Philips orderlines of 2015, to define the optimal car basestock levels for all SKUs. Hereby we vary on the storage capacity of the car between 1 and 5 m<sup>3</sup> with steps of 1 m<sup>3</sup>. Per combination of country and modality, the logistics costs of Scenario 0 and the minimum logistics costs per cost bucket in Scenario 1 with their corresponding optimal car stock size, review period length, and number of needed FSEs, are listed in Appendix K and Appendix L respectively. In this chapter, we will analyze the main differences in logistics costs of Scenario 0 and Scenario 1, and analyze the influence of the car stock size and review period length.

### 7.1 Overall Analysis

Figure 7 shows the normalized absolute decrease in logistics costs per country and modality of Scenario 1 compared to Scenario 0. Per country and modality, the optimal set of car stock size, review period length, and number of FSEs is chosen, which accounts for the lowest logistics costs. It shows that the introduction of car stocks is profitable for every country and modality, except for the modality MR in France. The modality DXR accounts for the highest average percentual decrease in logistics costs, followed by the modality US.

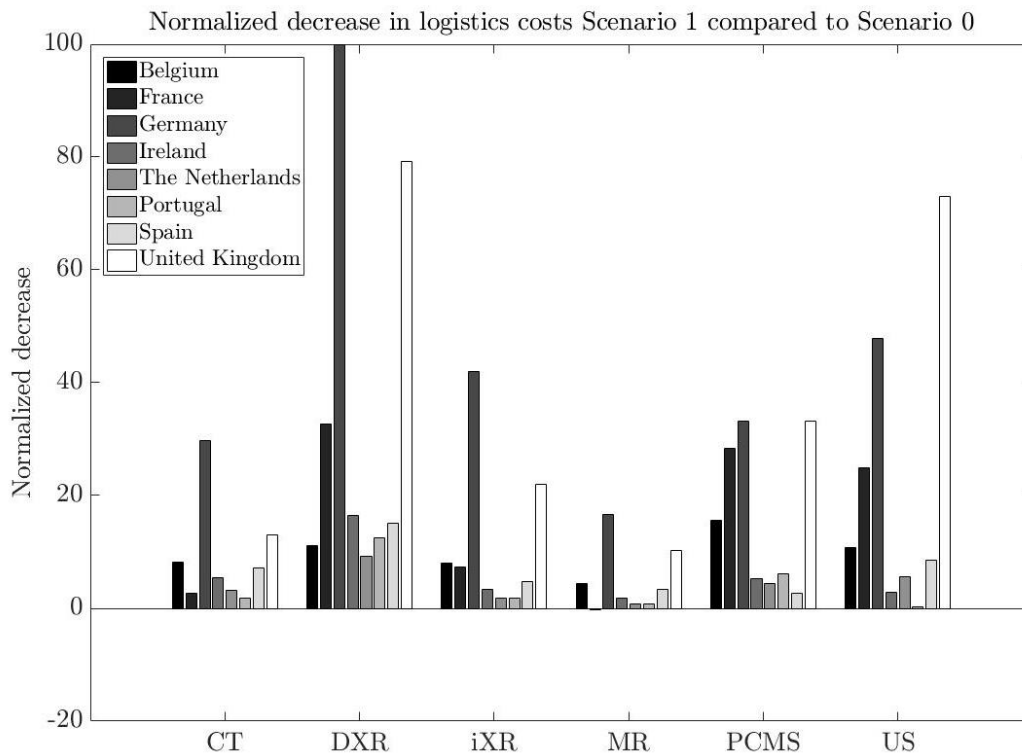


Figure 7: Normalized decrease in logistics costs per country and modality

To find out which cost buckets cause the change in logistics costs in Scenario 1 compared to Scenario 0, we plotted the normalized decrease per cost bucket in Figure 8. It shows that the

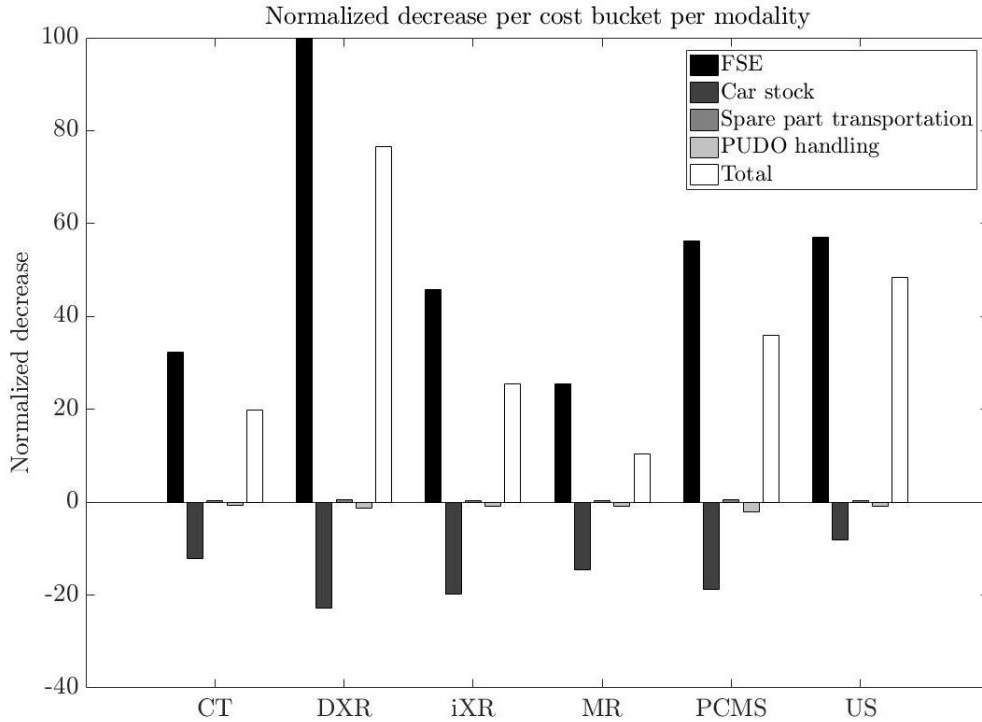


Figure 8: Normalized decrease per cost bucket per modality

decrease in total logistics costs for all modalities is caused by the major decrease in FSE costs. Although car stock inventory holdings costs is a new cost bucket in Scenario 1 compared to Scenario 0, the increase of this cost bucket does not outweigh the decrease in FSE costs. Furthermore, we see that PUDO handling and outbound transportation costs have an almost neglectable effect on total logistics costs.

Besides logistics costs savings, the introduction of car stocks also has an effect on the customer service rate. As explained in Chapter 3, in Scenario 0 an FSE always needs to visit a customer site twice for the scoped orderlines. In Scenario 1, if a car stock SKU is available at demand, an FSE only needs one customer site visit. In Figure 9, we plotted the percentage of these single-visit maintenance service calls in Scenario 1 for each country and modality. It can be seen that in Scenario 1, the percentage of single-visit service calls varies between 9,9 and 46,6%, with an average of 20,9%. We can thus conclude that the introduction has a significant influence on the customer service rate for all countries and modalities. Furthermore, in Appendix L it can be seen that the total number of FSEs is decreased by seven in Scenario 1 compared to Scenario 0, distributed over all modalities except for the US modality. This decrease is mainly in Germany, which accounts for a decrease of five FSEs.

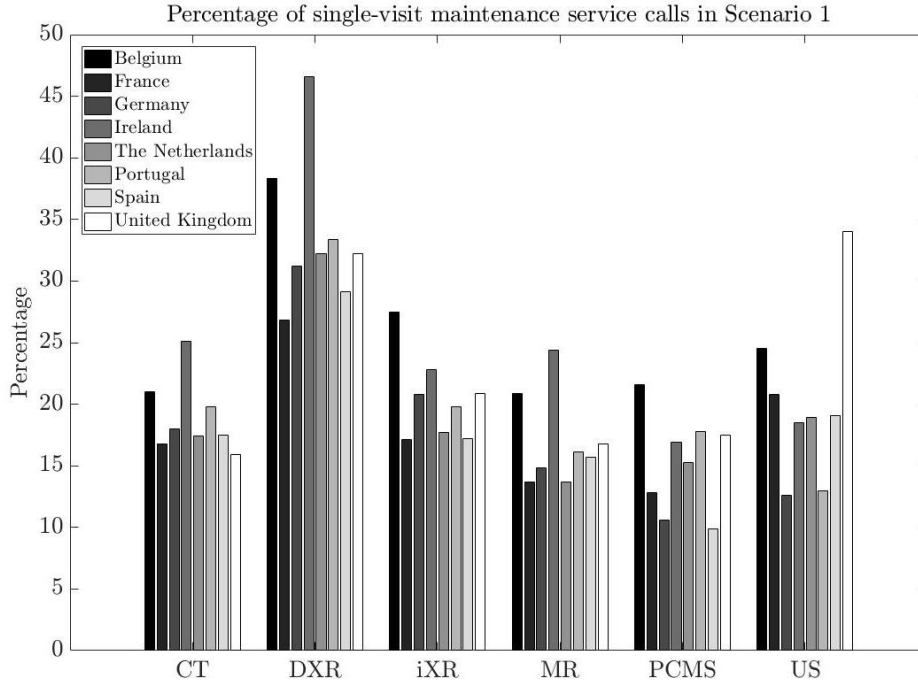


Figure 9: Percentage of single-visit maintenance service calls in Scenario 1 per country and modality

## 7.2 Car Size Analysis

To gain insight into the effect of the maximum storage capacity of the car on the absolute decrease in logistics costs per modality, we plotted the normalized total logistics costs summed per modality for five different car sizes in Figure 10. It can be seen that for each car size, the modality DXR shows the highest absolute decrease. Furthermore, Figure 10 shows that for a car size of  $1 \text{ m}^3$ , the introduction of car stocks causes a decrease in total costs for all modalities. However, for bigger car sizes, the total decrease in total costs per added  $\text{m}^3$  decreases. We can thus conclude that the biggest ‘bang’ is made at the introduction of the first  $\text{m}^3$  of car stock for all modalities.

To find out which costs buckets cause the decreasing effect in logistics costs for car sizes bigger than  $1 \text{ m}^3$ , we plotted the normalized decrease per cost bucket and modality for a car size of  $3 \text{ m}^3$  in Figure 11. In this figure, it can be seen that this is caused by a much higher increase in car stock inventory holdings costs compared to the decrease in FSE costs. The modalities PCMS and MR even show an increase in FSE costs. Again, we see that PUDO handling and outbound spare part transportation costs have no major influence on the total logistics costs.

Overall, we can conclude that the main trade-off of the introduction of car stocks is thus the decrease in FSE costs compared to the increase in car stock inventory holding costs.

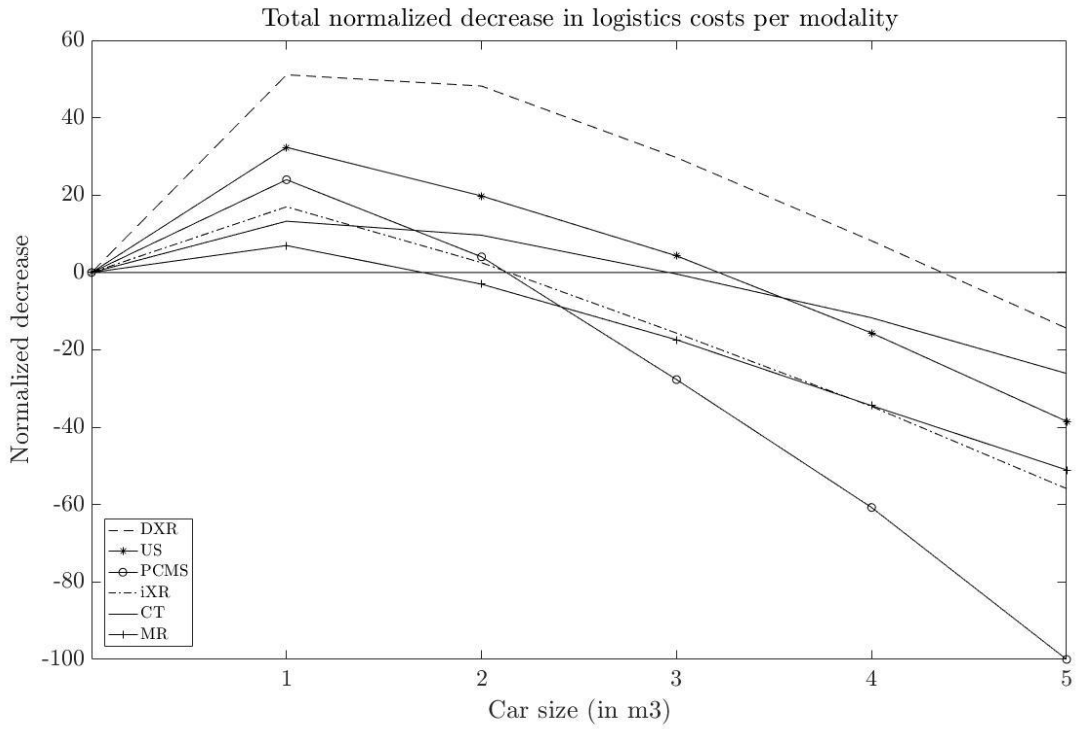


Figure 10: Total normalized decrease in logistics costs per modality

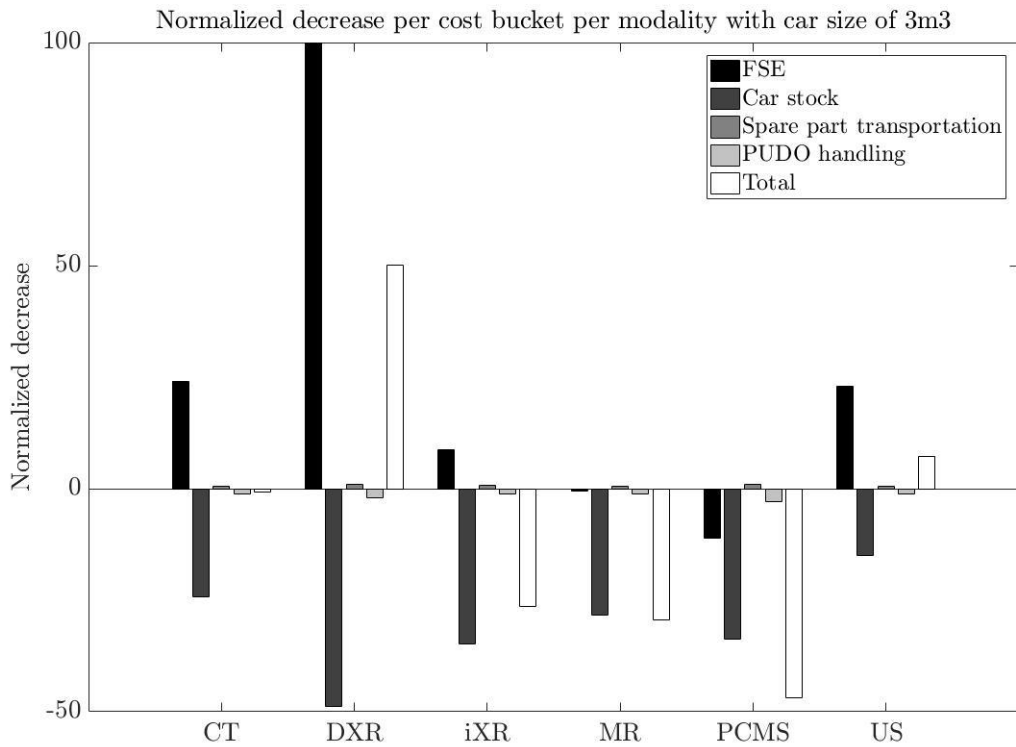


Figure 11: Normalized decrease per cost bucket per modality with car size of 3m3

### 7.3 Review Period Length Analysis

To find the effect of the car stock review period length on logistics costs, we performed a sensitivity analysis on the DXR modality in Germany with a car size of 1 m<sup>3</sup>, which shows the highest absolute decrease of every country and modality. It is important to remind that a shorter review period length implies more car stock replenishments, and thus a higher fill rate for each car stock SKU.

Figure 12 shows the normalized change in car stock inventory holding costs. It can be seen that a longer review period length causes lower car stock costs. This is intuitive, since a longer review period length causes less car stock replenishments, and thus lower on-hand inventory per car stock SKU. This results in lower car stock inventory holding costs.

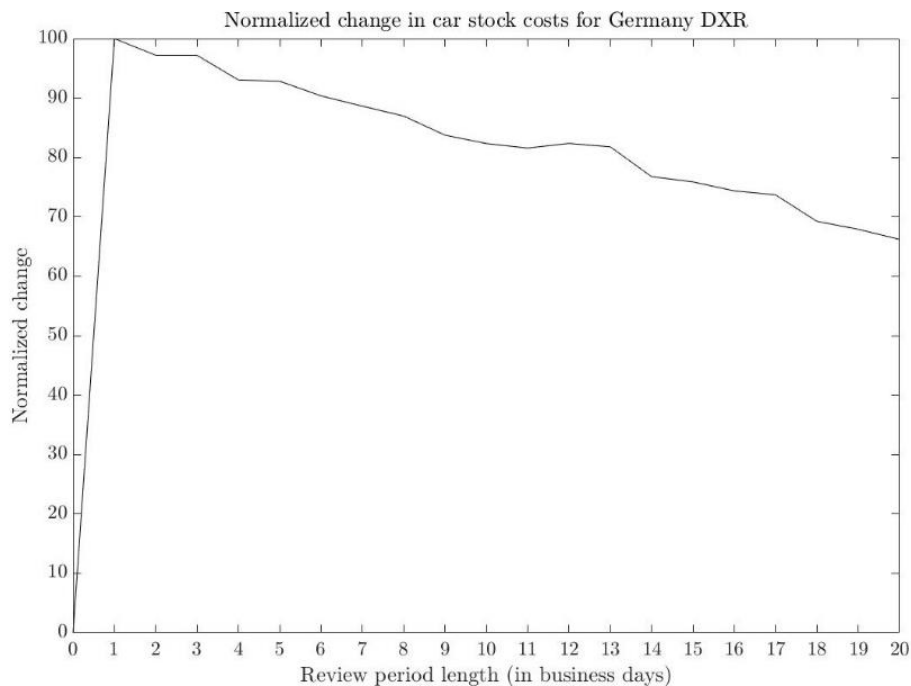


Figure 12: Normalized change in car stock inventory holding costs for Germany DXR

In Figure 13, the normalized change in FSE costs are visualized. It shows that an increase in review period length first shows a decrease in FSE costs, but these costs start increasing for longer review periods. As explained in Chapter 5, the FSE costs bucket consists of customer visits, car stock replenishment, and out-of-scope travelling costs. Since lower review period lengths cause a higher fill rate for the car stock SKUs, customers visit cost will decrease, since there is a higher chance that a demand can be fulfilled out of the car stock. However, lower review period lengths also cause more car stock replenishment, which increases the FSE travelling costs for these not order-related PUDO replenishments. Out-of-scope travelling costs are only influenced by the change in FSE travelling costs, and will thus not change when varying over the review period length.

The change in PUDO handling and spare part transportation costs when varying on the review period length show intuitive results, as shown in Figure 14 and Figure 15. A higher fill rate per car stock SKU, caused by lower review period lengths, results in higher PUDO handling costs since more SKUs will be sent to PUDOs for the car stock replenishments. Furthermore, shorter

review period lengths cause an decrease in spare parts transportation costs, since more SKUs will be sent via the UPS economy mode.

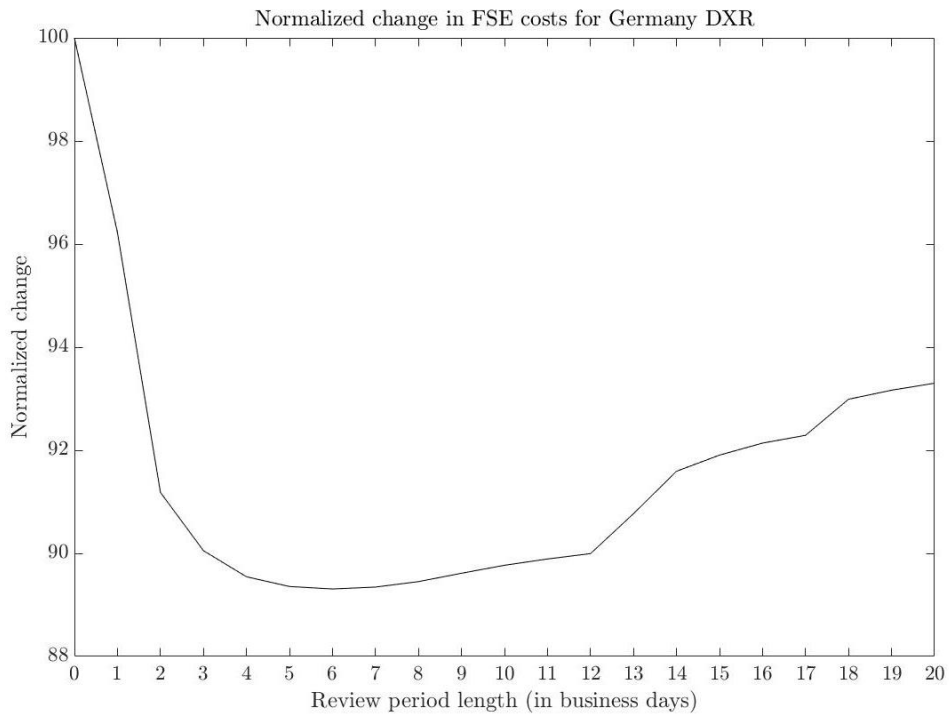


Figure 13: Normalized change in FSE costs for Germany DXR

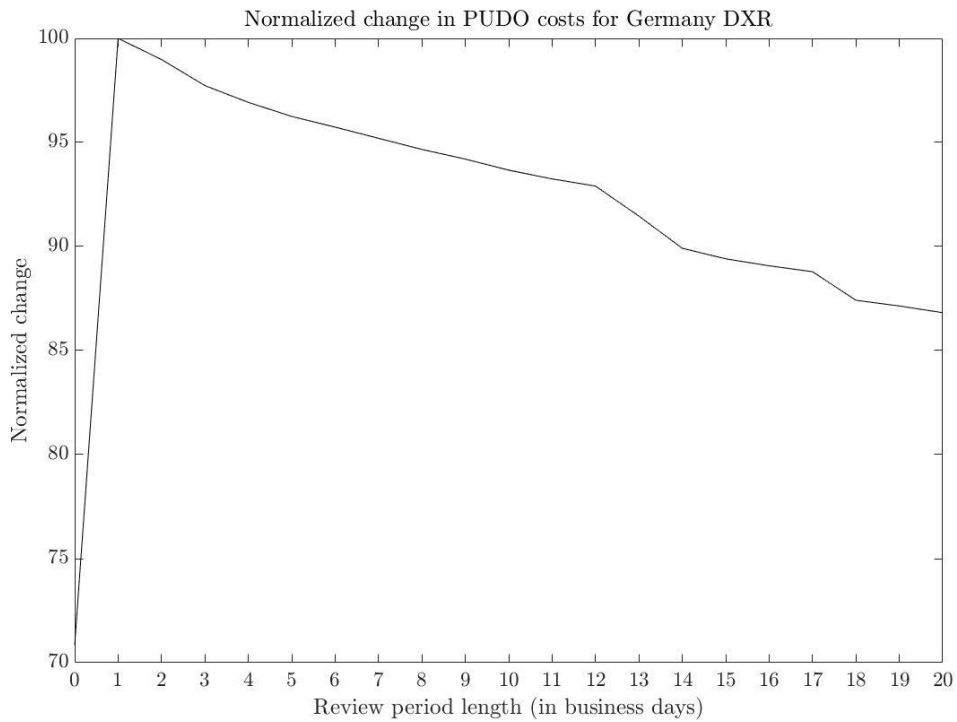
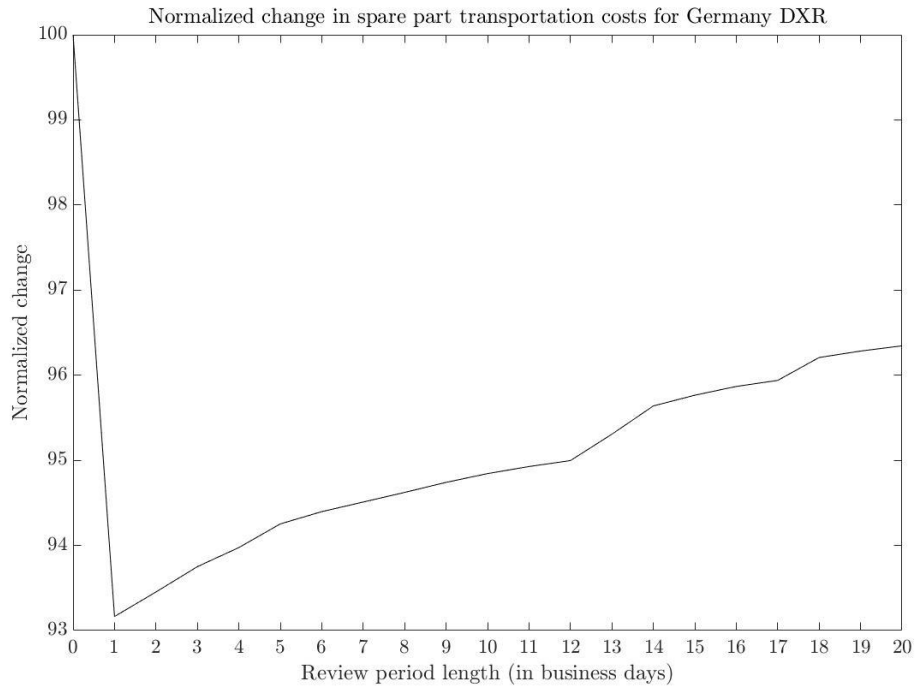


Figure 14: Normalized change in PUDO handling costs for Germany DXR





*Figure 15: Normalized change in spare part transportation costs for Germany DXR*

Taking into account that we concluded that PUDO handling and outbound spare part transportation costs have no major influence on total logistics costs, we can conclude that there exists a single optimal review period length, due to the decreasing effect on car stock inventory holdings costs for longer review period lengths and the found tipping point in FSE costs.



## 8 Conclusion

---

In this chapter, we draw the main conclusions of this thesis. Furthermore, we mention the limitations of the conducted research and provide several recommendations for both Philips and future research.

### 8.1 Main Findings

The research objective was defined as: *'Modelling the use of car stocks in the current Philips service process to evaluate the effect on logistics costs.'*

In Chapter 5 we concluded that the change in logistics costs in Scenario 1 compared to Scenario 0 is caused by four main cost buckets: outbound spare part transportation costs, PUDO handling costs, FSE costs, and car stock inventory holding costs. At the introduction of car stocks, PUDO handling costs, FSE PUDO visits, the FSE hourly travel rate, and car stock inventory holding costs will increase, whereas outbound spare part transportation costs, FSE customer visits, and order-related collection of spare parts will decrease. The in- and outbound handling costs at the RDC, PUDO handling rate, and inventory holding cost rate are assumed to remain unchanged at the introduction of car stocks.

In Chapter 7, we implemented the proposed optimization algorithm of Chapter 6 for every country and modality on the scoped Philips orderlines of 2015. Based on the performed analysis, we can draw the following conclusions:

- The introduction of car stocks causes a decrease in total logistics costs for all modalities, except for the modality MR in France, which shows a minor increase in logistics costs. Total annual absolute and relative saving are █████ Million EUR and 3,4% respectively. The highest absolute decrease in total costs were found for the DXR modality, especially in Germany and the United Kingdom, with savings up to █████ (20,1%) and █████ Million EUR (8,0%) per year respectively.
- The decrease in logistics costs of Scenario 1 compared to Scenario 0 is caused by the major decrease in FSE costs. Although car stock inventory holdings costs is a new cost bucket in Scenario 1 compared to Scenario 0, the increase of this cost bucket does not outweigh the decrease in FSE costs. Furthermore, we see that PUDO handling and outbound transportation costs have an almost neglectable effect on total logistics costs.
- The introduction of car stocks has a significant influence on the customer service rate for all countries and modalities, since if a car stock SKU is available at demand, an FSE can directly perform the needed maintenance, saving a second visit to the customer site the next business day. The percentage of single-visit service calls in Scenario 1 varies between 9,9 and 46,6% for the different countries and modalities, with an average of 20,9%.
- Based on the sensitivity analysis on the maximum storage capacity of an FSE car, we can conclude that the biggest 'bang' is made at the introduction of the first m<sup>3</sup> of car stock for all modalities. Furthermore, it was found that the main trade-off of the introduction of car stocks is the decrease in FSE costs compared to the increase in car stock inventory holding costs.

- Based on the sensitivity analysis on the car stock review period length, we can conclude that there exists a single optimal review period length, due to the decreasing effect on car stock inventory holdings costs for longer review period lengths and the found tipping point in FSE costs, which makes both too short and too long review periods not favorable.

## 8.2 Limitations

This research knows several limitations which we would like to highlight.

First of all, in Chapter 2 we excluded the LDC and FSL warehouses from the research scope. However, these warehouses account for the most emergency outbound orders, which are delivered by taxi. Since the outbound spare part transportation costs related to these taxi deliveries are much higher than the currently used UPS express transportation mode, the use of car stocks would also be interesting for this type of orders.

Furthermore, the research is in several cases limited by the available data on FSEs. First, in this research it is assumed that every FSE is only assigned to one modality, but in practice FSEs can be assigned to more than one modality. Second, it is unclear what the exact hourly FSE rate is, and which costs are included in this hourly rate. Therefore it was hard to estimate the increase in hourly travel cost rate in case bigger FSE cars are needed. Third, the total FSE travel times or spare part collecting times for each order were often unclear or not available. Therefore, we had to roughly estimate these FSE hours.

## 8.3 Recommendations

Although we concluded that the introduction of car stocks decrease the logistics costs for all modalities, the modality DXR clearly showed the highest absolute savings. Since the modelled cost buckets only approximate the reality, our main recommendation is to perform a pilot implementation in a single country for this modality. It is recommended to perform this pilot in either Germany or the United Kingdom, since those countries both have a high number of orderlines and showed the highest absolute decrease in logistics costs at the introduction of car stocks.

Second, it is recommended to conduct further research on the emergency taxi deliveries. Although these orders only represent a small percentage of the total orders, the introduction of car stocks could possibly cause high savings on the high outbound transportation costs related to these emergency orders.

Third, since we concluded that the outbound spare part transportation costs have an almost neglectable influence on total logistics cost, it would be interesting to research what the effect is of the use of the express transportation instead of the economy transportation mode for the car stock replenishment. This would cause slightly higher transportation costs, but decreases the spare parts in the carstock order pipeline, and thus increases the SKU fill rate for car stock SKUs.

Furthermore, since clearly the highest savings are made due to savings in total FSE hours at the introduction of car stocks, it is recommended to gain more insights in the current FSE

process and corresponding costs. Then, a more accurate estimation of the change in FSE costs could be given.

For future research, it would be interesting to perform several other case studies on the introduction of car stocks in comparable businesses to find out which part characteristics, service processes, and spare part distribution network setups are the most suitable for the introduction of car stocks.



# Bibliography

---

- Adan, I., & Resing, J. (2015). Queueing Systems [lecture notes]. Eindhoven University of Technology.
- Beckenbach, E.F. (1948). Convex Functions. *Bulletin of the American Mathematical Society*, 54(5), 439–460.
- Huyps, E. (2015). *Integrated inventory and transportation mode selection at Philips Healthcare* (Master Thesis). Eindhoven University of Technology.
- Karush, W. (1957). A Queueing Model for an Inventory Problem. *Operations Research*, 5, 693–703.
- Kranenburg, A.A., & Van Houtum, G.J. (2007). Cost optimization in the  $(S - 1, S)$  lost sales inventory model with multiple demand classes. *Operations Research Letters*, 35, 493–502.
- Rijk, P. (2007). *Multi-item, multi-location stock control with capacity constraints for the fieldstock of service parts at Océ* (Master Thesis). Eindhoven University of Technology.
- Royal Philips N.V. (2016). *Annual Report 2015*. Amsterdam.
- Van Houtum, G.J., & Kranenburg, A.A. (2016). *Spare Parts Inventory Control under System Availability Constraints*. New York: Springer.





## Appendices



## **Appendix A – Spare Part Orders per Maintenance Type**

---

Omitted due to confidentiality.

## **Appendix B – PUDO-eligible SKUs**

---

Omitted due to confidentiality.

## **Appendix C – CM Orderlines per Country**

---

Omitted due to confidentiality.

## **Appendix D – CM Orderlines per Modality**

---

Omitted due to confidentiality.

## **Appendix E – Car stock suitability per modality**

---

Omitted due to confidentiality.

## **Appendix F – Full-time FSEs and overall FSE hours**

---

Omitted due to confidentiality.

## Appendix G – Denoted Variables

---

Variable	Description
$c^f$	Hourly FSE travel cost rate in Scenario 0 in EUR
$c^h$	Percentage of SKUs value that represent the average inventory holdings costs
$c_i$	Cost price of SKU $i$ in EUR
$c^p$	PUDO handling costs per orderline in EUR
$c_i^{t,ec}$	Economy transportation costs of order SKU $i$ in EUR
$c_i^{t,ex}$	Express transportation costs of order SKU $i$ in EUR
$c^{trav}$	Hourly FSE travel cost rate in Scenario 1
$C(\mathbf{S}, r, f)$	Summed costs of all cost buckets in EUR, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$C^F(\mathbf{S}, r, f)$	Total FSE travel costs in EUR, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$C^H(\mathbf{S}, r, f)$	Total inventory holding costs in EUR, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$C^P(\mathbf{S}, r, f)$	Total PUDO handling costs in EUR, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$C^T(\mathbf{S}, r, f)$	Total outbound spare part transportation costs in EUR, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$F$	Set of possible number of hired full-time FSEs, with $f \in F$ and $f = f^{cur}$ in Scenario 0
$h^{coll}$	Average time an FSE spends on collecting a spare part at either a PUDO or the customer site
$h^{cust}$	Average return travel time of an FSE to a customer site in hours
$h^{repl}$	Average collecting time of a car stock replenishment at a PUDO in hours
$h(\mathbf{S}, r, f)$	Number of in-scope FSE travel hours, under a given set of basestock levels $\mathbf{S}$ , review period length of $r$ and number of hired FSEs $f$
$h^{full}$	Total annual working hours of a fulltime FSE
$H^{other}$	Total annual number of out-of-scope FSE hours not spend on travelling
$H^{out}$	Total annual number of out-of-scope FSE hours
$H^{trav}$	Total FSE travel hours on out-of-scope orders
$I$	Set of SKUs, with single SKU $i$ ( $\in \{1, 2, \dots,  I \}$ )
$M_i$	Total demand rate of SKU $i$ , with demand rate per FSE $m_i = \frac{M_i}{f}$
$OH_i(\mathbf{S}_i)$	Expected on hand inventory of SKU $i$ , under a given set of car basestock levels
$p_i$	Probability that in Scenario 0 a SKU $i$ will be sent to a PUDO
$q$	Probability that a demand is assigned to an FSE, with $q = \frac{1}{f}$
$R$	Set of possible car stock review period lengths in business days, $r \in R$

$S_i$	Basestock level of car stock for SKU $i$
$t^{car}$	Mean leadtime of a car stock replenishment order in business days
$t^{ec}$	Leadtime of UPS economy transportation mode in business days
$t^{ex}$	Leadtime of UPS express transportation mode in business days
$v_i$	Volume of SKU $i$ in $cm^3$
$V^{car}$	Maximum effective storage capacity of an FSE car in $m^3$
$V(\mathcal{S})$	Volume of FSE car used in $m^3$ , under a given set of basestock levels $\mathcal{S}$
$w^f$	Total working days per FSE per year
$X_i$	The total number of SKUs $i$ that are at a given moment in time in order for the car stock of an FSE
$\beta_i(S_i)$	Item fill rate of SKU $i$ , under a given basestock level $S_i$
$\theta_{r,f}$	Logistics costs corresponding to the optimal set of basestock levels as defined by the optimization algorithm for a given review period length of $r$ and number of hired FSEs $f$

---

*Table 2: Description of all denoted variables*

## Appendix H – FSE Hours per country and modality

---

Omitted due to confidentiality.

## Appendix I – Variance of Order Quantities

---

<i>Variance of order quantity</i>	<i>Number of SKUs</i>	<i>% of total SKUs</i>
0	██████	82,77%
0-0,25	██████	9,57%
0,25-0,50	██████	1,00%
0,50-0,75	██████	1,00%
0,75-1	██████	0,96%
>1	██████	4,70%
<i>Total</i>	██████	<i>100%</i>

*Table 3: Variances of order quantities of all SKUs*

## Appendix J – Minimum Number of FSEs in Scenario 1

---

Omitted due to confidentiality.

## Appendix K – Logistics Costs of Scenario 0

---

Omitted due to confidentiality.

## Appendix L – Logistics Costs of Scenario 1

---

Omitted due to confidentiality.

