MASTER

Measurement and reduction of CO2 emissions of the logistical processes in Philips

Koc, H.

Award date:
2010

Link to publication
Measurement and Reduction of CO$_2$
Emissions of the Logistical Processes in Philips
by
Hande Koc

BSc Industrial Engineering — Bogazici University 2008
Student identity number 0667764

in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

Supervisors:
Dr. T.Tan, OPAC, TU/e
Prof.dr.ir. J.C. Fransoo, OPAC, TU/e
Mark Didden, CSO, Philips
Simon Braaksma, CSO, Philips
Subject headings: supply chain management, carbon dioxide emissions, transportation, consumer electronics industry, stock control
ABSTRACT

This master thesis investigates the factors which have an impact on carbon dioxide emissions resulting from transportation activities. The determinants of the transparency of the logistical carbon footprint are discussed and suggestions for increasing the transparency of Philips’ emissions are presented. Several opportunities to decrease transport related carbon emissions are identified and assessed in terms of their estimated impact, feasibility and cost. Most promising options for Philips are determined as increasing load factor, transport type shift/intermodal transportation, increasing forecast accuracy and inventory management. The impacts of most promising options on emissions are analyzed in detail. Insights and recommendations for implementation of the analyzed options are presented.
PREFACE

This Master Thesis report is the result of my graduation project for the Master program Operations Management and Logistics at Eindhoven University of Technology. This project took place for seven months from February 2010 to August 2010, at Philips under Corporate Sustainability Office in Eindhoven, Netherlands. I would like to devote this page to thank all people who have contributed to this thesis.

First of all, I would like to thank my first supervisor from TU/e, Tarkan Tan for his contribution to this project. His feedbacks, guiding suggestions and professional support were very valuable for me and assisted me throughout the project. Our discussions at our phone call meetings significantly contributed to the progress of this project. Additionally, I would like to thank Jan Fransoo (second supervisor) for his feedbacks and opinions.

Within Philips, I would like to thank Mark Didden, Simon Braaksma and Henk de Bruin for giving me the opportunity to work on this project in their company. I especially want to thank Mark and Simon for their useful guidance throughout the project, for all the time they spent for our discussions and their contributing feedbacks about the project.

Additionally, I would like to thank Green Logistics Team members for their guidance on my research dimensions and for the information they provided. Furthermore, I would like to thank to the employees of HID Business Unit, especially Karel Biesmans, for providing me useful data and answers to my questions. Also, I would like to thank my colleagues in Corporate Sustainability Office for creating such a pleasant work environment. It was a wonderful experience for me to have this internship at CSO with them and I learned a lot from them about several different issues on sustainability.

I also want to thank to people who are not directly involved in this project. I would really like to thank my parents and my brother for always being there for me and supporting me all the time. Furthermore, I owe many thanks to Recep Meric Gungor for his help and support during the project.

Hande Koc
September 2010
MANAGEMENT SUMMARY

Environmental issues due to the climate change have been in the centre of interest of business management in the last few years. Therefore, some international agreements are put in place in order to limit the emissions. As a result, there is a growing interest among researchers to investigate abatement options for logistics-related carbon emissions.

In Royal Philips Electronics, sustainability is an integral part of the company philosophy. Therefore several companywide programs are running which try to improve sustainability performance of the company. EcoVision 4 is one of them and with this program Philips has a commitment to cut down its total operational carbon footprint by 25 percent by 2012, compared to base year 2007. Since 33 percent of the emissions are originating from their transport operations, transport emissions need to be reduced significantly in order to reach above mentioned targets.

This project is held in cooperation with Philips Corporate Sustainability Office and aimed to point out improvement potentials in measurement and reduction of logistical carbon dioxide emissions.

It was found by a preliminary analysis that the majority of the logistical carbon footprint comes from air transport and expresses air shipments. Inventory management, including stocking and shipment decisions, is the main driver of express air shipments.

Considering the abovementioned facts, the project aimed to come up with answers to the following research questions:

1) “How to provide more transparency to the carbon footprint of the logistical processes of Philips?”

2) “How can CO₂ from goods transport be decreased?”

3) “What is the relationship between inventory & transportation decisions and emissions?”

4) “How to implement possible CO₂ reduction options?”

To answer the first research question, the transparency of the carbon footprint of the company was assessed considering the current data availability and accuracy of the estimations. The methodology utilized in Philips for emission calculation process is very limited and allows the company to observe only a few reduction alternatives on final results. Therefore, application of NTM methodology to Philips’s data would be a solution to provide more visibility to the carbon footprint; hence it could give the opportunity to decrease emissions with improvements made on several dimensions. However, considering the decentralized supply chain structure of the company and the inexistence of a companywide logistical database, it is very difficult to collect and process detailed logistical data in order to come up with transparent emission calculations. In addition, most of the data that are necessary for detailed calculations are not present in the databases, e.g. per shipment and load factor data. It is argued that the performances of NTM methodology and GHGP are similar at the most aggregate level in terms of transparency in settings where no detailed data is available, but NTM becomes superior when additional data becomes available. Since the availability of data in the company is very limited centrally and an IT-based database or software which can cumulate and process all data from different sectors is not existent, the calculations made using NTM methodology will not even be transparent in this setting. Thus, if the company does not make additional
investments, or sign specific agreements with LSPs or carry out projects to increase the transparency in transport activities, it is not possible for them to benefit from the opportunities provided by more transparent calculation procedures.

Additionally, several suggestions were presented in order to increase the accuracy of their estimates and incorporate more variables into calculations such as load factor as a part of chargeable weight, routing for road etc. Besides, collaboration with LSPs plays an important role, because a notable amount of data which Philips does not hold is available at LSPs. Fortunately, LSPs are willing to collaborate in terms of data sharing and offering intermodal transportation, for the sake of environmental issues.

As a second step in the research, to find answers to the second research question, a benchmark study and a literature review were conducted and several interviews were held. As a result of these studies, general reduction options were identified and then assessed in terms of their feasibilities, costs and estimated impacts on emissions. The analysis brought out the following evaluation graph:

![Evaluation of Abatement Options](image)

As can be seen in the above figure, most promising options in this analysis are: modal shifts/intermodal transportation, inventory management, increasing forecasting accuracy and increasing load factor; and then these options were investigated with more detail on the selected deep-dive scope. The results of the analysis revealed that inventory management may allow up to 37 percent improvements in the carbon emissions. Also, the other options will have an impact between 3 and 10 percent impact on the total emissions.

In addition, the majority of the emissions were found to be originating from a small number of lanes. Thus, any adjustments done over these lanes in terms of mode change and intermodal transportation or any kind of control over LSPs, might lead to notable changes in global emission results. Therefore special attention should be paid to those lanes.

For finding an answer to the third research question, which investigates the relationships between inventory management and emissions, a Markovian and a simulation model were constructed in order to gain more insights on the relationship between inventory replenishment decisions, forecasting accuracy and carbon emissions. The studied system is a forecast-driven supply chain because of the global dispersion of the supply chain operations. Economical reasons entail such
dispersions; however this creates a number of operational difficulties. During the analysis, forecast errors were found to have a notable impact on the emissions, because higher forecast error variability triggers emergency shipments. It was found beneficial for the company to keep the Coefficient of Variation values of the forecasting errors lower than 0.5 so as to avoid steep increases in emissions.

In addition, the impact of inventory replenishment decisions on carbon emissions was found to be considerably high and mostly the emission savings go hand in hand with the cost savings. Looking at the overall inventory strategies of Philips, it can be said that special attention has been paid to decrease the inventory levels aiming to decrease inventory costs and working capital. However this policy increases emergency shipments considerably, which in turn results in a high logistical carbon footprint. Therefore, for products groups whose holding cost value is extremely small compared to emergency shipment prices, alternative inventory strategies might be better which try to keep as much inventory as possible in order to eliminate emergency shipments. Notable reductions in emissions can be obtained by holding more safety stocks. In addition, for the studied system, it was found that if the emergency orders were given in a reactive manner at the end of the week, the impact of forecast errors would be eliminated and the emissions can decrease up to 20 percent for the current safety stock policy, with negligible differences in service levels (less than 0.5 percent).

The fourth research question aims at shedding light on to the implementation of the discussed issues. Main points can be summarized as follows:

- In order to increase transparency, increasing the accuracy of the estimates and taking into account additional variables are necessary. Using NTM will provide the company with a more transparent carbon footprint. Therefore, more variables such as vehicle type information, load factor etc. should be considered in the estimations. This can only be made possible by an IT based infrastructure which can handle the storage and processing of notable amounts of data.

- Emissions could be reduced by focusing on a small number of lanes and by collaborating with LSPs to improve emissions in those lanes. In addition, new KPIs could be defined which can be used as additional criteria in LSP selection procedure.

- To increase forecasting accuracy, weekly distribution of sales could be analyzed and weekly forecasts could be generated instead of generating monthly forecasts and simply dividing them to four for weekly operations planning.

- In order to increase load factors, this statistic can also be defined as a KPI which is already planned to be done in the Lighting sector. In addition, alterations made on shipment frequencies might result significant increases on load factor.

- Safety stocks at the RDCs can be increased to feasible and reasonable levels to decrease the probability of requiring emergency shipments. This will result in substantial savings besides a notable decrease in emissions that result from express air shipments.
Table of Contents

ABSTRACT ......................................................................................................................... iii
PREFACE .............................................................................................................................. iv
MANAGEMENT SUMMARY ................................................................................................. v

Table of Contents ................................................................................................................ viii

CHAPTER 1: PROJECT CONTEXT ...................................................................................... 1
1.1. General Background ...................................................................................................... 1
1.2. Company Description ................................................................................................. 2
   1.2.1. General Information about Philips ........................................................................ 2
   1.2.2. Products and Organization .................................................................................... 2
   1.2.3. Corporate Sustainability Office ............................................................................ 3
1.3. Report Structure ......................................................................................................... 3

CHAPTER 2: RESEARCH DESIGN ....................................................................................... 4
2.1. Problem Definition ...................................................................................................... 4
2.2. Research Questions .................................................................................................... 5
2.3. Project Approach and Methodology .......................................................................... 5
2.4. Project Scope ............................................................................................................ 7

CHAPTER 3: TRANSPARENCY OF CARBON FOOTPRINT .................................................. 8
3.1. Data Availability ........................................................................................................ 8
3.2. Insights from Data Collection Procedure ................................................................ 9
3.3. Assessment of the Carbon Emission Calculation Procedure in Philips ..................... 11
3.4. Improvement Suggestions ........................................................................................ 13

CHAPTER 4: CARBON EMISSION REDUCTION OPTIONS ............................................... 16
4.1. Preliminary Observations .......................................................................................... 16
4.2. General Reduction Opportunities ............................................................................. 18
   4.2.1. Delivery Route ..................................................................................................... 18
   4.2.2. Chargeable weight .............................................................................................. 20
   4.2.3. Transport Mode Decision ................................................................................... 22
   4.2.4. Efficiency of Transport ...................................................................................... 23
   4.2.5. Other Factors ..................................................................................................... 24

CHAPTER 5: ANALYSIS ON THE DEEP-DIVE SCOPE ....................................................... 27
5.1. Information on the Deep-dive Scope .......................................................................... 27
   5.1.1. Supply Chain Structure ....................................................................................... 27
   5.1.2. Shipment Process Description ............................................................................. 27
   5.1.3. Current Emissions Figures .................................................................................. 28
5.2. Impact of Abatement Options on the selected scope: .................................................. 30

CHAPTER 6: EMISSION CONSTRAINED INVENTORY MANAGEMENT .......................... 35
6.1. Optimization Model ................................................................................................... 35
6.2. Solution of the Model: ............................................................................................... 39
   6.2.1. Solution Procedure ............................................................................................. 39
   6.2.2. Characteristics of the Cost Function ..................................................................... 39
   6.2.3. Optimization and Sensitivity Analysis .................................................................. 40

CHAPTER 7: SIMULATION MODEL ................................................................................... 42
7.1. Model Assumptions ..................................................................................................... 42
7.2. Explanation of the Model .......................................................................................... 43
7.3. Verification and Validation ......................................................................................... 44
7.4. Tradeoff between Inventory and Emissions ................................................................. 45
7.5. Optimization Using OptQuest .................................................................................... 47
7.6. Scenario Analyses ...................................................................................................... 49
7.7. Sensitivity Analysis .................................................................................................... 51
CHAPTER 1: PROJECT CONTEXT

This document is the report of the master thesis project titled *Measurement and Reduction of Carbon Emissions of the Logistical Processes in Philips*, finalizing the MSc. Operations Management and Logistics program in Eindhoven University of Technology, under the sub-department of Operations Planning, Accounting and Control. The project was carried out in the Corporate Sustainability Office of Royal Philips Electronics in Eindhoven, Netherlands.

This chapter gives brief information about CO₂ emissions and Philips.

1.1. General Background

Environmental issues due to the climate change have been in the centre of interest of business management in the last few years. The warnings made about increasing earth temperature, increasing levels of pollution and decreasing levels of the natural resources attract more attention to the issue everyday and force authorities to take preventive actions to reverse the damaging effects of humankind to the earth.

Global Warming, which is defined as the increase in the average earth’s temperature, is caused by the increasing concentration of greenhouse gases in the atmosphere and it has catastrophic effects on the nature such as ocean acidification, sea level rise etc. (O’Sullivan, 2009). Therefore some international agreements are put in place in order to limit the emissions. The most well-known agreement is the Kyoto Protocol which is a legally binding commitment for reduction of six greenhouse gases. Under this Protocol, the European Countries must reach a level 8 percent below their emission level of 1990, during the period of 2008 to 2012 (Kyoto Protocol, 2008).

Even though the Kyoto protocol restricts the emissions of all of the six greenhouse gases, there is a consensus among scientists that CO₂ is the major contributor to global warming because its impact is much bigger than the other gases (Nordhaus, 1991; CRSC, 2009). Global CO₂ emissions need to be reduced significantly to stabilize atmospheric concentrations at sustainable levels. In order to tackle the undesired level of CO₂ emissions, EU countries have started the EU Emission Trading Scheme (EU ETS) in January 2005 which is the first international trading system for CO₂ emissions in the world and it currently covers several sectors and over 12,000 companies representing around 45 percent of the Europe’s CO₂ emissions (Reilly & Paltsev, 2005). Since carbon emissions have a price under this scheme, CO₂ is different from other greenhouse gases in the sense that it can be considered as a cost/benefit component for the firms.

Since 2005, significant emission reductions are obtained from the improvements that are achieved in the sectors included in the EU ETS. This has increased the relative contribution of transportation activities to the overall emissions, since transportation is not included in the EU ETS as a sector of concern. 24 % of the worldwide CO₂ emission is originating from transport activities and the demand for energy grows most rapidly in this sector (European Commission, 2007). European Commission predicts that, under the current regulatory environment, emissions growth stemming from transportation activities will be responsible for the entire growth in CO₂ emissions between 1990 and 2030 (Fransoo et. al, 2010; European Commission, 2007). Without appropriate action, CO₂ emissions resulting from transportation are expected to be doubled in 2020 compared to 1990. This results from the increase in the transportation movements due to the globalization of supply chains, and an increase in the energy efficiency alone is not enough to balance this (Hoen et. al., 2010). Therefore the EU decided to include the aviation sector in the EU ETS. Legislation will only cover flights to and
from Europe. Airlines will be required to monitor their carbon emission starting from 2010 and will be fully included in the scheme after 2012. A directive for sea shipping is also planned to be published soon. Even though the prices for the emissions of aviation have not been set yet; they are expected to have similar cost values with the existing emission prices since the European Commission tries to integrate aircraft operators into the existing EU ETS as far as possible. As a result of the abovementioned issues, there is a growing interest among researchers to investigate abatement options for logistics-related carbon emissions. However existing literature on the relationship between emissions, and supply chain structures and operational policies is still very limited. In order to shed more light on the subject, this master thesis project is carried out in Philips and aimed at identifying main factors influencing logistics-related carbon emissions.

1.2. Company Description

In this section Philips is introduced, including information about its products, organization and the Corporate Sustainability Office.

1.2.1. General Information about Philips

Royal Philips Electronics was founded in Eindhoven in 1891 as a manufacturer of incandescent lamps and other electrical products. Nowadays it has 155 production sites around the world and a multinational workforce of approximately 123,800 employees in more than 60 countries. The company is headquartered in Amsterdam, Netherlands and has three divisions (sectors): Healthcare, Consumer Lifestyle and Lighting. Being the world’s third largest consumer electronics maker, the company is the global market leader in home healthcare, lamps, lighting electronics, automotive lighting, electric shavers, electric male grooming, automated external defibrillators, patient monitoring systems, cardiac ultrasound, cardiovascular X-ray and professional luminaries (Annual Report, 2008). Their goal is to satisfy the needs of their customers with their technological innovations by delivering on their brand promise “sense and simplicity”.

1.2.2. Products and Organization

At Philips, each sector has its own supply chain structure and resources. Even within a sector, supply chain networks differ depending on the business units. Since the overall structure is highly decentralized, each business unit can be considered as an independent agent which controls its own operations with its own resources. As part of their strategic program, Philips is simplifying its supply chain structure by merging several of its business units. The long term goal of the program is the unification of sectors, standardization of the company activities/processes, bringing all its product divisions under one umbrella which will enable unlocking synergies by leveraging competencies and resources across the company (Anufrienko, 2010). As part of the company’s vision of 2010, the organizational structure was simplified by forming three main sectors. Details on those sectors and information on their supply chain structure in Europe can be found in the table below:
### Table 1.1: Business Areas and Supply Chain Europe

<table>
<thead>
<tr>
<th>Sectors:</th>
<th>Business Areas:</th>
<th>Supply Chain Europe:</th>
</tr>
</thead>
</table>

1.2.3. Corporate Sustainability Office

Sustainability is an integral part of the way of Philips’s business and it is on the management agenda (Annual Report, 2009). The emphasis on sustainability goes well beyond complying with the regulations, and involves a company voluntariness to include social and environmental concerns in all parts of its business operations and interactions with the stakeholders. Philips Corporate Sustainability Office (CSO) is part of the embedded governance structure that Philips uses to drive sustainability throughout the organization (See Appendix I). CSO works in coordination with the divisional sustainability directors and employees from other functions, drives the execution of the company’s sustainability action programs, and provides coordination at the Philips Group level. CSO delivers the sustainability report which is integrated with the Annual Report as from 2008. This report contains information about Philips’ sustainability performance of the previous year and targets for the next years in addition to the current status of the environmental programs such as EcoVision III and EcoVision4, Chemical Management, Green products and Philips Supplier Sustainability Involvement Program etc. Details on these programs can be found at the website of the company under the sustainability link. Thus, it is obvious that Philips places great importance to environmental considerations and tries to improve processes to achieve its performance targets.

1.3. Report Structure

This report is structured as follows: The following chapter introduces the problem situation and the research methodology being adopted to tackle this problem. In Chapter 3, current measurement methods of CO₂ emissions, and suggested improvements in the measurement in order to increase the transparency are discussed. In Chapter 4, CO₂ reduction opportunities are introduced, as a result of interviews and a literature research. Then the deep-dive scope is specified and improvement opportunities are explained further for two of the selected options in Chapter 5. Third, and the most important of the reduction options, inventory management, is discussed in Chapters 6 and 7. The effect of inventory management on emissions from transport activities is analyzed by using a Markovian model in Chapter 6 and a simulation study in Chapter 7. Finally, practical insights developed from the studies are given in Chapter 8, with concluding remarks and suggestions for further research.
CHAPTER 2: RESEARCH DESIGN

This chapter explains the design of this research in detail. First, the problem setting is explained and the problem definition is presented in section 2.1. Then, the research questions that are formed to find solutions to the stated problems are given in section 2.2. In section 2.3, the methodology used and the way of approaching to the problem are explained. Final section gives information about the scope of analysis.

2.1. Problem Definition

As explained before, Philips places great importance to sustainability and considers it as one of the seven strategic drivers of the company. Starting from the year 1994, Philips has put environmental improvements at the heart of its business activities with a series of action programs. Currently, Ecovision 4 is running and with this program Philips has committed to improve its energy efficiency by 25 percent and reduce its total operational carbon footprint by 25 percent until year 2012, all compared with the base year 2007. Operational carbon footprint comprises of four main components: manufacturing, logistics, non-industrial and business travel. Details on operational carbon footprint can be seen in Appendix II.

Nowadays, manufacturing activities of Philips have lower energy density and several improvements have been done so far on energy management which in turn reduced their contribution to overall emissions. However current performance of the company in terms of reductions of operational carbon footprint is still well below its targets. Emissions from logistical activities make up 32 percent of the overall operational carbon footprint as seen in Figure 2.1 (Annual Report, 2009) and therefore needs to be reduced significantly in order to attain targeted reductions. Majority of the logistical carbon footprint is coming from air transport and express air shipments and the level of emissions per sales volume stayed approximately the same between years 2007 and 2009, as depicted in the figure below; even though several reduction measures were taken to put a halt on air usage.

![Figure 2.1: Historical Carbon Footprint Figures of Philips calculated using GHGP](image-url)

In addition to the corporate consciousness to reduce emissions, new legislations which are put in place by EU, such as the inclusion of aviation in EU ETS, put pressure on Philips to take more effort to reduce its carbon footprint. The impact of emission caps to the aviation sector is expected to be an increase in the shipment prices. Even though the prices for the emissions of aviation have not been set yet; they are expected to have similar cost values with the existing emission prices since European Commission tries to integrate aircraft operators into the existing EU ETS as far as possible. Because of the abovementioned facts and the inexistence of low-hanging fruit to pose as a solution, Philips is willing to explore abatement levers and improvement opportunities especially for the high emission levels of air transport. New improvement options should be investigated and evaluated in
terms of their relative impact on overall emissions together with their feasibility. However the current methodology used in Philips to calculate emissions makes it impossible to see the impact of several reduction options on emissions. The underlying reasons for this will be discussed in Chapter 3. Therefore one of the aims of this study is to come up with concrete suggestions to increase the transparency of emissions from logistical operations in Philips. In addition, the company is willing to investigate the relationship between emissions and inventory management. Even though a companywide air freight reduction program was initiated, which introduced several control steps aiming to reduce total volumes shipped via air, the company could not see a significant reduction in emissions. The companywide policies which aimed at decreasing inventory levels to cut costs during the crisis period may be the reason why emissions from air stayed the same. Therefore a detailed analysis, which depicts the trade-offs between inventory and emissions, is essential.

2.2. Research Questions

In order to find a solution to the above mentioned problems, the aim of this project is designated as to find out ways to increase the transparency in the logistical carbon footprint, use this transparency to explore general reduction options for Philips and to investigate the impact of inventory management on logistical carbon footprint. After having several initial meetings and discussions with Philips employees, research dimensions are determined and each dimension is split into smaller steps to assure manageability. These steps are then translated into research questions and sub-questions that are given below:

1. How to provide more transparency to the carbon footprint of the logistical processes of Philips?
   1.1. Which data is necessary to improve estimations?
   1.2. To what extent is this data available?
   1.3. How does the transparency change when the NTM methodology is utilized?
2. How can CO₂ from goods transport be decreased?
   2.1. What are the general methods to reduce CO₂ from logistics?
      2.1.1. What do other companies do about this issue?
      2.1.2. Which options can be found in the literature?
      2.1.3. What are the effects of ongoing projects related to logistics on emissions?
   2.2. Which reduction alternatives are most promising?
3. What is the relationship between inventory & transportation decisions and emissions?
   3.1. To what extent do stock-outs, forecasting errors and other exceptions affect the transport mode choice decisions and emissions?
   3.2. What are the effects of inventory related decisions on CO₂ emissions?
4. How to implement possible CO₂ reduction options?
   4.1. What are the requirements for implementation?
   4.2. What are the possible impacts of the required modifications on business activities?

The main challenge is the fact that traditional logistics systems do not focus on the environmental concerns and generally focus on cost minimization and profit maximization (Daskin, 1985; Fransoo et. al., 2010).

2.3. Project Approach and Methodology

This project can be classified as Business Problem Solving (BPS) and it is design-oriented, performance-focused and client-centered since it is conducted in collaboration with a company. The
The ultimate goal of BPS projects is to improve the performance of the studied business system (Van Aken et al., 2005). Steps, which are to be taken, are given in Figure 2.2.

*CRSC Project: Carbon Regulated Supply Chains Project (CRSC, 2009)*

The first step of the research will contain interviews, literature research and data collection in order to provide more visibility to carbon footprint of Philips’ goods transport. As a second step, an appropriate emission calculation methodology which is applicable to Philips’ data structure will be identified. After this step; a dual approach will be adopted which consist of a general study and a deep-dive study. Firstly, general reduction options will be identified using information collected from literature, sustainability reports of peer group companies and logistic initiatives within Philips. Then a high level study which evaluates determined reduction options will be presented and each option will be evaluated in terms of abatement potential, feasibility and cost. Next, most promising options will be selected and their impacts will be discussed theoretically and numerically with the help of several analyses on a selected deep-dive scope. Finally the improvement options will be made more concrete by making suggestions on the implementation process.

Based on the study of Van Strien (1997) the steps in research projects can be seen in Figure 2.3:

---

**Figure 2.2: Research Approach**
Reflective cycle represents the company’s before-and-after considerations about the problem, and regulative cycle contains the actual problem solving actions. The regulative cycle has five basic process steps as it can be seen from Figure 2.3 given above. This project will mainly focus on the first three stages in regulative cycle, namely problem definition, analysis & diagnosis, plan of action. The fourth step, i.e. the intervention step will only be included partially since interventions and evaluation of the proposed solution cannot be completed within the project duration. The regulative cycle starts with analyzing the problem mess to understand the problem and in the end, problem definition is made based on the agreement between the principal of the project and the student. Next step is the “analysis and diagnosis” step during which student tries to find out and understand the major causes and consequences of the problem. During the “plan of action” step, the student designs the solution for the problem and the associated change plan (Van Aken et. al., 2005).

2.4. Project Scope
Only CO₂ emissions are within the scope of this project. Therefore the analysis are solely based on CO₂ and there is a risk of increasing other types of emissions during the abatement processes; however this will not be investigated. In addition, the main focus will be the logistics activities of the company, therefore other factors included in operational carbon footprint calculation such as manufacturing, usage of product by consumers, disposal of the product etc. are out of scope. In order to narrow down the scope of the project to a level which can be completed within the project duration and considering the amount of data available on-hand, the main concentration is determined to be on Europe while evaluating the general reduction options. Therefore shipments from/to and within Europe are included in the analysis in Chapters 3, 4 and 5. Scope is further narrowed down in Chapter 5, by choosing a representative product group which will be explained in Chapter 5, because detailed parameter estimations are necessary for solving and soundly analyzing the model.
CHAPTER 3: TRANSPARENCY OF CARBONFOOTPRINT

This chapter is dedicated to find answers to the first research question which aims to explore the means to provide more transparency to the logistical carbon footprint of Philips. Firstly, in Section 3.1, the extent and the accuracy of the data used in the calculation process is investigated (research question 1.1); then in Section 3.2, the research that was made to explore the availability of the additional data is presented (research question 1.2) and in Section 3.3, discussions on the emission calculation methodologies which are applicable to Philips’ data structure are presented (research question 1.3). Finally, the chapter ends with improvement suggestions for increasing the transparency.

As mentioned in the problem definition, transparency of the carbon footprint is essential to evaluate the potential impacts of several reduction options on the final emission calculations. Transparency can simply be defined as: the detail level of the content of the data and how they are used in emission calculations. Increasing the transparency of the carbon footprint enables understanding the underlying structure of the emissions and allows detecting and improving the bottlenecks more easily. In addition, it also provides the company with an opportunity to observe the impacts of the possible improvements on the results. However, transparency necessitates the storage of detailed information about transport activities, and this may require a notable number of parameters to be stored in the databases, which in turn might create several data handling problems. In addition, collection of the additional data may require preliminary changes in the documentation. In the following section, the data availability in Philips is discussed.

3.1. Data Availability

In order to explore which data is necessary to improve estimations, at first an investigation is made to explore current data availability.

In Philips, data used in emission calculations is gathered from several different data sources. For example, road transport data in Europe is collected from eight different data sources each having a different template. In addition, the content of this data is limited to the cumulative weight and location information which is necessary for distance determination. Underlying reason for that is the inexistence of per shipment data since they do not store unique shipment numbers in the databases. In addition, some of the parameters that are necessary for very detailed calculations such as vehicle type, load factor etc. are known but not stored in the databases or simply not known because they are not very crucial for the ongoing processes. Even though it is possible to gather more detailed data from the employees who are in charge of concerned activities, such a data collection process requires extensive time and effort of the data collector considering the decentralized supply chain structure of Philips. Even when such detailed data are obtained, one could question the reliability and consistency. Therefore it is reasonable to use the information available in the central databases for carbon emission estimations even though it does not include details, and make assumptions accordingly during the identification of general reduction opportunities.

As mentioned before, carbon footprint of transport in Philips consists of three main components: air/express freight, road freight and sea freight. Emissions from rail transport are reported under road transport since rail usage is very limited. For each component different information is available; thus they will be explained separately.
Air/ Express Freight

Central data of air transport and express shipments are stored in separate files and both are obtained from the KPI (Key Performance Indicator) Reports which can be considered as reliable data sources since the data inside of these reports are used in business activities such as the payments done to the LSPs. Express shipments are always assumed to be made via air transport although for some lanes the actual mode of transportation is not known since Philips does not keep track of the transport mode information. For air transport, total weight of the shipments, the names of the origin and destination airports are available together with the number of shipments made on each lane. For express shipments only information on total transported weight and names of the origin and destination countries are available together with the number of shipments. Distances are estimated using the great-circle distance formula since longitude and latitude data are available for each airport used, and no information on the non-air legs of the shipments is available except the major lanes which were made available as a result of a previously conducted study in cooperation with Fontys University.

Road Freight

The road freight data of some business units (BU) is available at the central databases such as SAP. For other BUs, data files are requested from Insep which is a freight pay and audit company. For each transport lane in Europe, only the data on the cumulative transported weights of all shipments is available. Since the information of the number of shipments made on each lane is not available, per shipment information, which is necessary for making emission estimations more transparent, cannot be estimated with ease. In addition, the level of detail on the origin and destination of the shipments changes depending on the sector and business units. For some units, information such as postcodes, city names etc. are available which helps to make estimates about the distance travelled more correctly. However for some lanes, only the names of the origin and destination countries are available which decreases the accuracy of the estimates and hinders the analyst from observing the most polluting lanes clearly. No information on the routings, positioning distances and empty returns are available. Only the direct distances from the origin points to the destination points, which are mostly found by using maps.google.com, are available in an extensive database.

Sea Freight

Names of the origin and destination ports are available and the distance information is stored in a central database which is highly reliable but limited. In addition, data on the number of TEUs (twenty-foot equivalent unit) together with the type of containers is also available. The data is coming from Uplift Reports; therefore includes reliable information since the same data is used in other business activities as well.

To conclude; per shipment data and information on vehicle type, load factor, routing and empty trips are not available centrally which are necessary for increasing the transparency of the emissions.

3.2. Insights from Data Collection Procedure

The general characteristics of the central data available for all transport modes are summarized in section 3.1. In order to explore other sources of data and find out to what extent details are available, several interviews were scheduled with logistic service providers (LSPs) and relevant people within Philips. For the interviews with LSPs, initial documents which explain the input request were prepared and sent beforehand to the interviewee and teleconference meetings were held. For
The phone call interviews were standardized in order to get answers from the same directions; however interviews within Philips were low structured and several different issues were discussed without loss of focus on the main directions. The data collection procedure from the providers was very time consuming and ineffective. The response rate was very low, even though several reminders were sent to the providers. Since the project duration was very limited to try to collect detailed information on global transport data, the main aim on those meetings was to discover the limits of the detail level which LSPs are willing to share with Philips, rather than collection of these data points as a whole. In other words, data availability was investigated for future purposes, not for this project. Even though the interviews held with Philips employees did not have a standardized format, they were beneficial in obtaining crucial information. In addition, the interviews done with LSPs provided useful and fundamental information. The most important findings that are attained from the interviews can be summarized as follows:

- For road transport, the directness of the shipment, in other words routing between origin and destination points, depends on the transport flow type. Different transport flows can be seen in Appendix IV. For mainstream flows shipments are generally FTL (Full Truck Load), made directly from the origin point to the destination point and the most commonly used vehicle types are in the group of larger and less polluting vehicles such as standard trailers, mega trailers and swap bodies among which standard trailer is the most frequently used vehicle. However for downstream flows, information on routing and vehicle type is not available. Philips only knows the vehicle type which picks the product up from its DCs and this information is not always stored. However the vehicle type changes during the transportation process since the goods are first transported to the consolidation centers of LSPs and then sent to their final destinations consolidated with other products to same destinations. The only condition which Philips controls in the contracts with LSPs is the appliance to EURO Norms; however CO₂ is not included in the scope of EURO Norms (Van den Akker, 2009). In addition, no information on loading degree is stored since majority of the shipments are not dedicated to Philips but shared with other companies.

- Majority of the service providers (7 out of 9) stated that they would be willing to cooperate with Philips on solving environmental issues. They are open to discussions about sustainability and offer intermodal options on several lanes. It is not possible for the LSPs to share fuel consumption data with their customers. However they are willing to share data on loading degrees and the transport vehicle types with Philips. Since per shipment information is not available centrally within the company, matching between lanes and vehicle types per each shipment is not possible. Therefore, information about the most frequently used transport types on major lanes is requested. Although LSPs stated that they are open to share data and necessary information with Philips, majority of them stated that this process requires a fair amount of data to be collected, checked and processed and they are not willing to allocate their resources to do such a job. For sea freight, three out of five contracted providers stated that the most frequently used vessel types are Panamax and Post Panamax for the routes Philips indicated. For air transport, just one provider out of four provided requested data and the most frequently used aircraft types are B747-400 Freighter and A330-300 Belly in that case. However, they claim that indicating most frequently used vehicle types does not provide reliable information since vehicle types cannot be unique for one origin/destination as it depends on several different factors, some of which can be seen in Table 3.1.
To sum up, research presented in sections 3.1 and 3.2 shows that even though sustainability is claimed to be an essential part of the company’s business philosophy; the concern on the sustainability of the transportation activities is limited. No information is available companywide on the sustainability performance of the vehicles used during transportation process and information on routings is very limited since transport is outsourced to third parties and it is the common assumption that LSPs are optimizing their own processes. Also, it is obvious that the main concentration is not on sustainability but on costs and delivery timeliness of the shipments. But additional information that is necessary for detailed analysis is available at the LSPs and can be requested to improve transparency.

In the light of the findings about the availability of the data and characteristics of the transport processes; an assessment of current calculation procedure is made which includes the comparison of the current methodology with the NTM methodology and presented in the following section.

3.3. Assessment of the Carbon Emission Calculation Procedure in Philips

Philips bases its carbon emission estimations on ton-km approach of GHG (Greenhouse Gas) Protocol. Since vehicle type information is limited, they use one emission factor common for all sea shipments, one for road transport and three different emission factors for air depending on the length of haul. More information on the calculation methodology in Philips can be seen in Appendix V. The strengths and weaknesses of this methodology can be summarised as follows:

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collection is manageable</td>
<td>Limited transparency</td>
</tr>
<tr>
<td>Data handling is not so difficult</td>
<td>Impossible to see the impacts of several reduction options on results</td>
</tr>
<tr>
<td>Data is highly reliable for sea and air transport</td>
<td>Aggregation Bias</td>
</tr>
<tr>
<td>Calculations are simple and do not take much time</td>
<td>Simplification Bias</td>
</tr>
<tr>
<td>Applicable to non-European countries</td>
<td></td>
</tr>
<tr>
<td>Provides the company with an opportunity to benchmark its carbon emissions with its competitors since the majority of them is also using the same methodology</td>
<td></td>
</tr>
</tbody>
</table>

One of the most important features of Philips’s GHG based method is that it is used commonly across the industry; therefore it provides the company with an opportunity to benchmark emissions with competitors. Also, its application is simple and manageable without the necessity of extensive effort for data collection and handling. However, it is apparent that the method is not sufficiently transparent as explained before. Also, there are biases hidden in the calculations. Aggregation bias can be observed when no specific distance information is available and country to country distances are used together with the cumulative weights. A numerical example of this error type can be seen in Appendix VII. And simplification bias stems from taking one single emission factor for all lanes even though in real life their coefficients might be different from each other.
In addition, compared to the updated versions of GHG Protocol (2005) and NTM (the Network for Transport and Environment) methodology, Philips’ calculation methodology is very limited. Therefore, this lack of transparency restricts the company to see the results of several reduction alternatives on emission values. The comparison of the methodology utilized in CRSC (Carbon Regulated Supply Chain Project, 2009) which is based on NTM method and the current methodology applied in Philips in terms of the variables included in calculations, together with the abatement dimensions that are affected by each variable is given in Table 3.3.

Table 3.3: Comparison of the Philips’s method with CRSC method

<table>
<thead>
<tr>
<th>Philips (GHG 2003)</th>
<th>Abatement Dimension</th>
<th>CRSC’s NTM based method</th>
<th>Abatement Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>Changes in the distances by changes in the supply chain network and routing</td>
<td>Distance</td>
<td>Changes in the distances by changes in the supply chain network and routing</td>
</tr>
<tr>
<td>Cumulative weight</td>
<td>Changes in the weight/chargeable weight of products by packaging initiatives, postponement, technological advances etc.</td>
<td>Terrain factor</td>
<td>Changes in the region of the shipment by changes in the supply chain network and routing</td>
</tr>
<tr>
<td>Non-air and non-water legs of shipments</td>
<td>Changes in the distances by changes in the supply chain network and routing</td>
<td>Road type</td>
<td>Changes in the region of the shipment by changes in the supply chain network and routing</td>
</tr>
<tr>
<td>Transport mode</td>
<td>Changes on transport mode with modal shift and intermodal transport</td>
<td>Empty trips</td>
<td>Changes in the empty trips and positioning travel by changes in the supply chain network and routing</td>
</tr>
<tr>
<td>Transport mode</td>
<td>Changes on transport mode with modal shift and intermodal transport</td>
<td>Transport mode</td>
<td>Changes in the vehicle type used in the process</td>
</tr>
<tr>
<td>Vehicle type</td>
<td>Changes in the vehicle type used in the process</td>
<td>Load factor</td>
<td>Changes in the load factor of the shipments</td>
</tr>
<tr>
<td>Load factor</td>
<td>Changes in the load factor of the shipments</td>
<td>Fuel type</td>
<td>Changes in the fuel type by using more environmentally friendly fuels such as alternative fuels etc.</td>
</tr>
<tr>
<td>Vertical Handling</td>
<td>Changes in the energy consumption during loading/unloading shipments</td>
<td>Temperature Control</td>
<td>Changes in the energy consumption for temperature control during shipment</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Changes in the energy consumption for cleaning the vehicle before/after shipments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The methodology used in emission estimations shapes the companies’ abatement strategies as can be seen from Table 3.3. If the number of variables included is limited, like the case in Philips, the company may concentrate on limited number of reduction options whose results are observable on outcomes. However as it can be seen above, the NTM method provides its users with several different abatement options which can be realized by changes in the values of the several parameters and it offers the possibility to calculate the emissions based on varying levels of detail. The three accuracy levels defined by NTM to measure their environmental performance are depicted in Figure 3.1 and can be summarized as:

- **General performance level (Level 1):** Average vehicles/vessels consuming average fuels and engine/motor specifications. The allocation of environmental burden is based on average load factors.
- **Defined performance level (Level 2):** Different vehicle types, average fuel consumption, engine/motor specification and load factor for each different vehicle type.
- **Detailed performance level (Level 3):** Different vehicle types, actual loading degrees and motor specifications.
A company can choose one of these levels and report its emissions based on the selected accuracy level. However it is always possible to go one step deeper and add details into calculations if more data becomes available. In fact, at the highest level (Level 1), estimations made using NTM and GHG protocol behave similarly in terms of transparency even though the coefficients may differ. The underlying reason of this behaviour is that at the highest level of aggregation, NTM assumes an average vehicle type and an average loading degree for all the shipments made by the same transport mode; which is quite similar to using a constant emission factor for each ton-km, as GHG assumes. Even though emission factors of road transport in NTM differs depending on the type of the roads used by the trucks such as motorway, urban and rural, a constant ratio of the utilized road types can be assumed for each shipment since detailed information is not available on this issue (CRSC, 2009). For air transport, unit emission per ton-km is decreasing with increasing distance in both methodologies. Hence, the transparency of the logistical carbon footprint of Philips can be considered as equivalent to the transparency provided by NTM’s Level 1, even though the emission coefficients of the two methodologies may differ, as can be seen from Appendix VI.

In order to make it more transparent, the company can consider changes necessary to transfer it to Level 2. Two protocols also behave similarly when the second accuracy level of NTM and GHG protocols with different vehicle types are compared. When the vehicle classification in NTM is mapped into the vehicle classification in GHG, it can be claimed that similar patterns exist in emission factors in both of the methodologies.

To conclude, it is quite reasonable to claim that in systems where very limited information is available; NTM methodology behaves like GHG protocol, but after some degree it becomes superior in terms of transparency with increased data availability. For Philips, it is possible to include more variables in the calculations; so the NTM methodology can be employed to increase the transparency of the carbon footprint of Philips by urging the company to gather more details for the estimations which in turn will help them to determine the bottlenecks in the logistical processes. However, emission coefficient defined in NTM methodology is only defined for European region, therefore application of this methodology on other regions may give poor results.

3.4. Improvement Suggestions

As mentioned in the previous sections, transparency of a carbon footprint is highly dependent on how accurate the estimates are calculated and to what extent factors that exist in real life are included in the system. Several improvement options which may provide more visibility are discussed below.
Creating focus on sustainability performances of transport activities: Currently main objective in transport mode selection is to achieve maximum service level with minimum cost. Even though sustainability is deemed as a strategic component of company policy, this understanding is not apparent in the operational decisions. New sustainability KPIs for transport services can be introduced and employed in order to benchmark the sustainability performances of different LSPs, to serve as an additional criterion on transport mode type and LSP selection, in addition to costs and other measures.

Collaboration with LSPs: Collaboration is seen as a means to increase efficiency and flexibility of operations and provides the companies with competitive advantage (Nyaga et al., 2010). It is shown that collaboration resulted in increased visibility, higher service levels and increased end-customer satisfaction (Daugherty et al., 2006). Research made via several interviews showed that more reliable and detailed data is available in LSPs and majority of them are willing to share information in order to reduce the environmental impact of transport activities. A similar application is present in the Health Care Division, where the road transportation service is done by a single LSP, which provides very comprehensive data including per shipment information, vehicle types, etc. In addition, providers are open to offer intermodal options, which create a negotiation direction to be considered as a collaboration opportunity.

Increasing the accuracy of the estimates: Repeated errors, even though they do not affect the comparison of yearly performances, might mislead the analyst about the relative contribution of some transport lanes or modes to overall emissions. Some suggestions for Philips to solve this issue are summarized in Appendix VIII.

Storing additional data: As mentioned before, availability of the data is a binding factor which influences estimations. Addition of each new variable to the calculations may result in a notable growth in the accuracy of the calculation; therefore special attention should be placed on the selection process of the variables to be included. Feasible alternatives to add can be transport mode type, distance, vehicle type information and loading degree data. All information needed is available, or easily reachable, at the parties who are in charge of those processes.

Standardize the process and divide the responsibility of calculations to many parties: As mentioned before, the owners of the transport processes can reach more detailed data. If estimation procedure is clearly defined, documented and standardized; roles and responsibilities in the calculation process can be divided to more parties. An example for this can be the creation of a generic calculation template and requesting from each DC to report its own emissions resulting from the transportation activities using this template. Empowerment of more people in calculations will in turn create more understanding and concern on sustainability and on the targets. In order to avoid overlapping or double counting, each DC might report the outflows from its facility in addition to the inflows except the inflows from other DCs. And unique ID numbers can be defined for each lane and utilized within each sector which in turn will help to analyst to eliminate such errors. It is also possible for the DCs to request detailed shipment data from the service providers and report emissions separately for each LSP. Since it is not possible to make a shipment via two different service providers, double counting errors can be prevented. The role of the analyst can then become more focused on interpreting the overall results and trying to discover main causes using input from several different sources, rather than calculating.

To conclude, it can be said that there is an opportunity for improving the transparency of the carbon footprint of Philips; but special effort and investments are necessary to achieve this. Considering the
current supply chain structure of the company, which is highly decentralized and has several different process owners, it is almost impossible for a single party to collect and process detailed data for each data source. Therefore if the company is willing to increase the transparency by increasing the level of detail in the calculations, the calculation process must be either supported by IT based infrastructure or can be standardized and distributed to parties with clear a calculation hierarchy and several rules. It is always possible to make logical assumptions for each detail dimension in the absence of data and to take into account real values if actual data is provided. Also, it can be concluded from the above discussion that the accuracy of the data for existing variables can be improved by additional effort, apart from the inclusion of new variables. This will in turn increase the accuracy of the results and make the most polluting lanes more transparent in the process. Even though NTM methodology is superior to GHGP in terms of transparency, given the current situation, GHGP’s performance at the most aggregate level is similar to the performance of NTM methodology and it is sufficient to reflect the yearly trend analysis.
CHAPTER 4: CARBON EMISSION REDUCTION OPTIONS

In this chapter, main findings from the literature research and the interviews with several employees are presented.

After the problem definition, the next step in regulative cycle as defined by Van Aken et. al. (2005) is the “Analysis and diagnosis” as can be seen in Figure 2.3. Before starting this step, preliminary analyses are made to have a better understanding of the current situation. Firstly, relative contributions of each road transportation lane within Europe to logistical carbon footprint are assessed and most polluting lanes are identified. Secondly, historical air and express shipments data are analyzed in order to find out the most polluting lanes and the reasons behind the steady behavior of the annual emissions despite the differences in sales volumes throughout the years, and preventive measures were taken to decrease the usage of air transport and findings are presented in Section 4.1. After that, a benchmark study was conducted in order to identify the relative position of Philips about logistical carbon footprint reduction strategies compared to its peer group members and competitors and the study revealed that some initiatives currently performed by other firms have not been applied yet by Philips. Details of the benchmark are presented in Appendix IX. As a third step, a literature survey and a research within the firm are conducted simultaneously to form a list of possible reduction alternatives and several reduction options are identified and presented in Section 4.2. In order to select the most promising ones, the relative impact of each reduction option on total emissions is estimated. Finally, most promising options are selected and analyzed in detail in the next chapters.

4.1. Preliminary Observations

Since the project duration is limited and recalculating Europe’s emissions using other methodologies such as NTM’s can take quite a lot of time, the emission values that were calculated by Philips based on GHGP are taken as the basis of the analysis presented in this section.

Road transport lanes in Europe:
The transport data of all business units are merged under the same database and lanes are distinguished depending on their origin and destination regions. For some lanes the lane codes are constructed as the combination of country ISO codes (ex: “NL”) and the two letters of the postal codes (ex: “56” for Eindhoven region) and for others they are formed by combining the origin and destination city names.
The overlapping between the lanes is checked manually; however there might be some human errors. The resulting analysis is sufficient to indicate the most polluting lanes and the trends in the overall footprint.

Figure 4.1: Percentage contribution of road lanes in Europe

The lanes are sorted in a descending order starting from the lanes with greatest contribution, ending with the lane with the least impact. Each lane in this list was numbered, assigning the most polluting

<table>
<thead>
<tr>
<th>Total Emissions</th>
<th>Number of Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>4</td>
</tr>
<tr>
<td>20%</td>
<td>10</td>
</tr>
<tr>
<td>50%</td>
<td>65</td>
</tr>
<tr>
<td>80%</td>
<td>617</td>
</tr>
<tr>
<td>100%</td>
<td>&gt; 19450</td>
</tr>
</tbody>
</table>

Table 4.1: Percentage Contributions
lane ID number 1. The scatter plot (Figure 4.1) depicts the relative contribution of each lane to overall road emissions of Europe. It can be clearly seen from this figure that there are some lanes whose impact is relatively much higher than the others. Also, the road data statistics are summarized in Table 4.1. It can be concluded that the majority of the emissions of road transport Europe are originating from the minority of the lanes, and this creates the opportunity to obtain significant gains on emissions by implementing improvements on a small number of lanes.

**Historical air and express shipment figures:**
In order to have an idea on the contribution of air transport lanes on overall air emissions; the same analysis, which is done previously for road lanes, is also conducted for the air shipment lanes. All air shipment data was gathered and the emission contribution percentages were found to be as given in Figure 4.2.

The results in Figure 4.2 and Table 4.2 indicate that the impacts of a small percentage of lanes on the total emission are much higher with respect to the others, as it was also found for the road lanes. Thus, it can again be concluded that the majority of the emissions of air transport are originating from the minority of the lanes, and a close attention should be paid to these lanes.

In addition to the analysis presented above, a benchmark analysis is conducted using historical emission results of air transport. A companywide project was started in 2007 which aims to reduce air shipments by introducing extra approval procedures in the fast transport mode request but emissions of air transport remained unchanged from year 2008 to 2009. A deeper look into air emission figures revealed that this increase can be attributed to the increase in the emergency inter-continental shipments.

### Table 4.2: Percentage Contributions

<table>
<thead>
<tr>
<th>Total Emissions</th>
<th>Number of Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>6</td>
</tr>
<tr>
<td>20%</td>
<td>15</td>
</tr>
<tr>
<td>50%</td>
<td>84</td>
</tr>
<tr>
<td>80%</td>
<td>369</td>
</tr>
<tr>
<td>100%</td>
<td>&gt; 6202</td>
</tr>
</tbody>
</table>

The usage of air

![Figure 4.2: Percentage contribution of all air lanes](image)

![Figure 4.3: Air transport Statistics for years 2007 to 2009](image)
transport has decreased from 2007 to 2009. However rising number of express shipments, which can be categorized as emergency shipments, counteract the decrease in the air freight volumes. The impact of this on emissions is visualized in Figure 4.4.

![Figure 4.4: Express Shipment Emissions (2008-2009)](image)

The peak points of CO₂ emissions on distance intervals can be seen in Figure 4.4, and these points correspond to inter-continental shipments because of their long distances. After the preliminary analyses are done to investigate general characteristics of the system, a comprehensive literature research is made whose results are presented in the next section.

### 4.2. General Reduction Opportunities

Logistical carbon footprint of a company is basically dependent on four major factors: the transport mode and type decision, characteristics of the delivery route, chargeable of the shipment and transport efficiency. Therefore, general reduction options are classified under four main categories. For some options, more than one category was reasonable; however they are listed under the category which best describe their function.

![Figure 4.5: Determinants of the Logistical carbon emissions](image)

And those factors are related with several different parameters which can be seen in Figure IX.1 in Appendix X. Each node in Figure X.1 represents a dimension which has an impact on the emitted carbon. Reduction options that are of interest, in fact originate from the possibility of an improvement on a given dimension. Since the impact of abatement options on the global logistical carbon footprint depends on to what extent they are applied, it is not plausible to try to explain them numerically so they will be assessed qualitatively on a 1 to 5 Likert scale, considering their target mode of transport.

#### 4.2.1. Delivery Route

The key characteristics of delivery network can be defined as: density of destinations (number of stops) and average distance travelled in between these stops (Daganzo et. al., 1985). The impact of the sequence of the visits on the traveled distance is a well-researched topic in operations
management area and many LSPs use several methods to reduce the length of haul since it is assumed to have a linear relationship with fuel consumption. Besides; geographical characteristics of the transport region, positioning distance, empty kilometers and traffic density are also important factors which have an influence on emissions. This section is dedicated to potential abatement opportunities which can be attained via possible changes on the above mentioned factors. Several options related with delivery route are listed below:

- **Moving production closer to the customers:** According to McKinnon (2008), the growth in the freight movement is more related with the increase in the transport distances, rather than the increase in the physical mass of goods in the expanding economy. Manufacturing of several products of Philips is taking place in low wage countries due to economic reasons; for European markets these countries are located in Eastern-Europe and the Far East. Moving production to those countries have resulted in greater transportation distances as well as operational challenges because of the increased lead times. In theory, it is possible to reduce the length of haul by reconfiguring production and distribution networks and sourcing products from local suppliers (McKinnon, 1999). An option for Philips to reduce carbon emissions is then to change its OEM suppliers or the locations of its factories so that they move closer to the customers. Since the major customers are located in Europe, the majority of the freight movement will be eliminated if the production of several components were moved to Europe. The elimination of inter-continental lanes may result in a decrease up to 60 percent in the total logistical carbon emissions since the contribution of those lanes to the total carbon footprint is calculated to be approximately 62 percent of all the emissions. Nevertheless it may seem unrealistic to consider such changes in the supply chain structure, only considering the environmental benefits they yield and ignoring the effect on costs.

- **Eliminate or reduce empty kilometers:** The term positioning distance stands for the distance traveled by the means of transport in order to reach the cargo location. For air, sea and rail transport, it is often assumed zero however it can take values such as 25 percent of the total distance travelled for road transport (CRSC, 2009). Therefore this adds extra carbon emissions on top of the regular transportation process. Empty return trips can be considered as a special case of positioning distance. Emissions from road transport are directly proportional to the distance travelled. Even though emissions from positioning and empty return trips are not reported in Philips, they are expected to have an impact on total emissions by 5 percent if an average of 20 percent positioning distance is assumed (NTM Road, 2009) since 25 percent of total emissions are originating from road transport and 20 percent of them are due to positioning/empty trips. Therefore it is wise for the company to take precautions to reduce them. In order to reduce the positioning distance, it is possible to choose the logistics service providers that are located close to the origin location of the cargo (CRSC, 2009). One can reduce empty returns by synchronizing shipments. Also pallet banking is a way to reduce empty kilometers travelled.

- **Pallet Banking:** In general, when there is a delivery from a DC to a customer, empty pallets are left at the location of the customer and considered as waste. It is then the customer’s responsibility to take care of them. However at certain occasions, Philips tries to retrieve empty pallets back. For example, BU Consumer Luminaires collects empty pallets back for reuse. Approximately 50 percent of all the pallets are collected and transported back to their original locations. The process of collecting empty pallets introduces additional transportation flows and as a result additional costs and CO₂ emissions. There are specialized companies throughout the world that delivers pallets where they are needed and take them back where they become released. The
released pallets are added to local stocks, so additional logistical flows to collect empty pallets are eliminated. For Philips, the impact on total carbon footprint is expected to be less than 1 percent since the empty pallet collection is only done for the lanes of some business units whose contribution to overall emissions are less than 1 percent; but it introduces substantial cost savings.

**Restructuring the Supply Chain and Route Optimization:** Restructuring the supply chain and optimization of the delivery route aims to eliminate the redundant steps in a transportation process and remove intermediaries to make it more efficient. According to a study conducted by Accenture, the abatement potential by network optimization is high and the optimization process is feasible. McKinnon states that the usage of computerized vehicle routing and scheduling can cut distances travelled by trucks by around 5-10 percent (McKinnon, 2008). However, minimizing the length of haul does not always lead to a reduction in the fuel consumption as the shortest route may involve a hilly terrain, urban areas and congestion (McKinnon, 1999) so one must also consider terrain factor so as to decrease emissions via route optimization.

As explained before, Philips has a decentralized supply chain structure and the company is willing to optimize it with restructuring. To this end, ONE Philips program is launched in 2008 to streamline Philips into a focused, agile and more cost-effective organization, which aims the unification of the sectors and standardization of the company activities and processes. As a part of this program, locations of several DCs are being altered and several routes were optimized which in turn is planned to lead to a better consolidated delivery service with less distance travelled in total; hence reducing the carbon emission values. In addition to the reduced distances, there will be a reduction of the energy consumption because several stock locations are being merged and this results in less electricity consumption; hence less CO\textsubscript{2}. In short, notable reduction in carbon footprint is expected to be attained as a result of this program.

### 4.2.2. Chargeable weight

The impact of chargeable weight is more related with the company’s share of the total emissions in a consolidated shipment, rather than the magnitude of emissions per shipment. If a shipment is not dedicated to the products of Philips, allocation of the total carbon emissions of a single journey to the parties involved (other customers of the LSP) is done depending on the chargeable weights; therefore measures to reduce chargeable weight are necessary to decrease emission share. Chargeable weight depends on the goods’ properties such as weight, volume and packaging material. The ratio of volume to weight is very critical since it plays a key role in chargeable weight calculations. In addition, the more efficient the transport means utilized, the less will be the chargeable weight per product. In this section, abatement opportunities which try to reduce chargeable weight of the shipments are introduced.

**Packaging Design Initiatives:** Sustainable packaging initiatives can contribute to carbon abatement across the supply chain substantially. Even though the impact on logistical carbon footprint is smaller compared to the abatement in the production phase of the life cycle, it is still expected to be more than the impact of modal shifts on global logistical emissions (Accenture, 2009).

The design of the packaging influences stackability, thus the loading degree of the shipment. In Philips, most relevant transport modes are airplanes, container ships and trucks; and most commonly used container type is standard 40ft container which has a minimum volume of
65.7 m³ and a maximum payload of 28,000 kg. Break-even density represents the minimum density above which weight becomes the limiting factor rather than the volume of the shipment. Break-even density of a container changes from 390 to 430 grams per dm³, because of the small fluctuations in the above mentioned features of a container. Truck types and maximum allowable weights vary a lot; hence the break-even densities vary between 190 to 350 grams per dm³. Air service providers define the chargeable weight coefficient as 167 gram per dm³, which can be considered as the break-even density. If the density of the product is below this limit, then a fictitious weight is calculated and used instead of real weight in calculations (Wever, 2009). When the air and express shipments data of previous years are analyzed, it can be concluded that volume is the critical factor in most of the shipments since chargeable weight is most of the time greater than the actual weight of the shipments. A case study in Philips with data of the years 2003 to 2006, including 203 products of the Consumer Lifestyle sector has revealed the same finding since most of those products are found to be below the break-even limits, as can be seen in Figure 4.6. This is an indication of the fact that volume is the most critical parameter in shipments; therefore needs to be optimized (Wever, 2009). Volume index, which is defined as the ratio of the volume of the box to the volume of the product is being utilized as a performance indicator which helps to explore the products that have potential for improvement. In order to attain the biggest gain on emissions; the supply chain structure and annual sales of a product should also be considered while deciding on the products for further improvement. A case study in Philips on a packaging design improvement on a certain product type showed that up to 75 percent reduction is possible. However, the impact on global emissions is expected to be less than 75 percent since the example used in the mentioned case study is an extreme one and not every packaging material can be eliminated as much as that one because of marketing related concerns.

**Postponement - Late Customization:** Postponement means some of the activities in the supply chain are not performed until the orders from the customers are received. Postponement can occur along the entire supply chain, from sourcing to final distribution depending on the product characteristics (van Hoek, 2001). Late customization is an example of the postponement concept, which stands for the postponement of the final customization of the products until the orders are received. When the order arrives, only the final assembly is performed which results in lower lead times to the customers. As mentioned before, productions of a vast variety of the products of the European market are taking place in the countries in Far-East like China. In the current situation, the products are produced and customized in Asia using the forecasts for each country and then shipped to Europe where they will be put on sales. The default transport mean of most of those shipments is ocean freight which has long transport times which increases the importance of the accuracy of the forecasts. If it were possible to delay the final customization of the products, then the impact of the forecasts on deliveries would be less. In the CL sector, the final customization of a product type is its packaging and the user manuals that are put inside of the boxes. If the products are shipped without any packaging materials and packaged by the local suppliers in Europe, the volume transported from Asia to Europe will be less and this will positively affect the CO₂ emissions. It also increases the flexibility of the process because the final customization is done later in time when the forecasts are more accurate or when the order is received. Since there is no detailed data available, the impact of late customization is not shown numerically; however it is expected to be medium since it may influence the majority of the products that are shipped on inter-continental lanes but the impact on cumulative weight may not be very significant.
4.2.3. Transport Mode Decision
Transport mode decision can be considered as the most important factor among all dimensions shown in Figure IX.1; because emission factor can vary tremendously depending on the transport modality and vehicle type, and it has a linear relationship with carbon emissions. Several factors have an impact on transport mode choice, some of which can be listed as: service level agreements, stock availability, product characteristics, external factors such as market conditions and characteristics of the transport mode type. In this part, factors affecting transport mode decision will be explained and improvement suggestions will be discussed.

Depending on the service level agreements with customers and the supply chain structure, the transport mode which satisfies the requirements is set as the regular mode of transport for a specific transport lane. The main determinant can either be product’s characteristics such as vulnerability or market conditions such as high price erosion. Except emergency situations, the regular transport mode is utilized. However when there is an urgency, alternative transport modes which are more expensive but have a shorter lead time are preferred in order to satisfy the service levels. Below, several abatement options related with transport mode decision are presented.

- **Modal shifts and Intermodal transport/ Co-modal transport**: One of the most frequently mentioned method in the literature is modal shifts to more environmentally friendly modes of transport. Co-modal transport, which means using several transport modes in parallel, is a special example of modal shifts. Modal shifts to rail and sea generally requires intermodal transport. One has to place special attention on the trade-off between the emission factors and the increased distances. Majority of the emissions are resulting from the transport movement on very few lanes at Philips as stated in Section 4.1; thus significant reductions can be observed by changes made on those lanes.

Thus, this option is perceived to be a promising one.

- **Vehicle type shift**: It is also possible to cut emissions by shifting to less polluting vehicle types. However the control of Philips over vehicle types is very limited. The vehicle type decision is under Philips control only for the mainstream road transport. Considering the fact that the most frequently used vehicle types which are Standard Trailers, Mega Trailers and Swap bodies are in the group of less polluting vehicles, the expected impact of a possible transport type shift is anticipated to be low. In addition it is really hard for a company to keep track of all those changes and take decisions accordingly. Because of the abovementioned reasons, this option cannot be classified as a promising one.

- **Inventory Management**: Tradeoffs exist, in terms of emissions and costs, between inventory and transportation decisions. Slower transportation modes emit less CO\(_2\) and are generally less costly but higher inventories should be held to meet the demand during the lead time. Even though notable emission reductions can be attained by changes in inventory replenishment strategies, this issue has not been explored deeply by researchers. As mentioned before, the inventory policy in Philips is to keep stocks at low levels. This results in emergency situations frequently and increases the number of express air shipments. It is proven by the yearly emission figures 2008 and 2009 that even though air transport is reduced, the increases in the express air shipments counterbalance the trend in normal air transport. And the underlying factors triggering the majority of these shipments are inventory driven. Thus reducing inventory by changing inventory decisions might result in significant emission savings. Therefore this option is included in the analysis scope.
For many products in the Consumer Lifestyle sector, obsolescence risk is too high or product lifetime is short; thus the general policy is to keep the inventory level low and to use fast transport modes to satisfy customer demand on time. Therefore Lighting sector where the market conditions are more stable is more suitable for analysis on the impact of inventory on emissions.

4.2.4. Efficiency of Transport

More efficient use of the capacity of the vehicles, results in less freight movements and thus less costs and less environmental impacts.

- **Increase load factor:** In principle, increasing the load factor means using the space more effectively. Loading degree depends on several factors such as the capacity of the vehicle, amount of products carried, country specific regulations on maximum payloads etc. Increasing the payload can cut emissions significantly (up to 28 percent) (Boere, 2010). However low-density products fill the vehicle space long before the maximum payload is reached. In addition, if products are vulnerable and not very stackable, achieving high load factors may not be possible. In mainstream logistical flows of Philips, higher load factors are attained compared to the downstream flows because most of the time the products of the same type are grouped and put on top of the same pallets. This makes the shape of the packages more flat and therefore has a positive impact on the stackability. However the downstream shipments in Philips are usually not full shipments, thus they are neither weight nor volume critical (Wever, 2009). Therefore the loading degree of the vehicles is highly dependent on the customer orders and can be altered with possible changes on delivery frequencies. This option has been chosen for further analysis in Section 5.2.

- **Use of double-deckers:** Usage of the double-deckers increases the available deck-area and grants the possibility of stacking the pallets on top of each other. This is beneficial in cases where product characteristics such as vulnerability are the limiting factor. However there are some problems associated with the usage of double-deckers. In order to load and unload the vehicles, equipments such as forklifts should be used. As a result, it takes more time and some amount of energy to fill the vehicles when double-deckers are used. In addition, one has to be aware of the trade-offs between the usage of energy during loading/unloading and the potential CO₂ emissions gain resulting from the increased load factor. Since the majority of the products are volume critical in Philips, using double-deckers might enable using the space more effectively; therefore it is suggested for decreasing emissions. A study revealed that using double-deckers can decrease emissions up to 43 percent (Ozsalih, 2009). Since this option is not applicable to all lanes and it is only valid for road transport, its impact on total emissions is not expected to be high.

- **Order consolidation:** The impact of order consolidation is the same with increasing the load factors. Order consolidation is already being applied in Philips. In the CL sector, the merge of the DCs now enables better consolidation of the orders. In addition, there are consolidation centers in Asia to consolidate shipments to increase the loads per shipment. Since there are already several programs on this topic, it will not be investigated further in this project.

- **Transport Sharing:** This option stands for the shipment consolidations with other companies. Henkel reduced the number of shipments made from one of its stock location by 30% by sharing the facility and transport service with other companies. For air, sea and road downstream, most of the shipments are not dedicated shipments; thus LSPs can combine them with the shipments of different companies based on the destinations of the deliveries. The control of Philips on this option is limited; therefore it will not be investigated further.
Energy efficient driving: Education of drivers on ways to drive more fuel efficiently can also reduce the carbon emissions. There are factors like low speed, less congestion, avoiding harsh acceleration and breaking etc. (Mc.Kinnon, 2008). However control of Philips over this option is also very limited; thus this option cannot be considered as a promising one.

Alternative Fuels: It is possible to substitute fossil-carbon-based fuels with alternative fuels such as compressed natural gas (CNG), biodiesel, ethanol, hydrogen etc. which in turn reduce CO₂ amount released to the air. The reduction chance by the usage of CNG is limited due to the fact that the vehicles have to be equipped with heavy tanks which in turn decrease the gains. The CO₂ reductions that can be attained by the usage of biodiesel and ethanol are in the range of 30-70 percent (International Transport Forum, 2008). However, the price of biodiesel is very high which makes it an unattractive option and the agricultural supply is not sufficient to produce ethanol currently, so the widespread usage of ethanol as a fuel is not possible. There are still doubts about the applicability of usage of hydrogen as the fuel because of the need for a supporting infrastructure, thus it is not used frequently (International Transport Forum, 2008). On top of all, the control of Philips over fuel usage is very limited, thus reducing emissions by shifting to less polluting fuel types cannot be considered as a promising option.

Vehicle improvements: Improving the vehicle efficiency creates substantial benefits in terms of environmental effects (Frey & Kuo 2007). According to a study performed by Accenture (2009), increasing road vehicle efficiency represents about 90 percent of the total carbon abatement potential. It is wise for Philips to keep track of the clean technologies that are used by LSPs and use this information as a factor affecting the tendering decisions. However considering the current focus on costs, the effect of this factor on tendering decisions might be very limited.

4.2.5. Other Factors
There are other improvement options in addition to the ones listed above. Since they do not aim any specific change on the specified dimensions presented before, they are listed under this category.

Decrease product returns: Returns of the products from customers also create a logistical flow which adds to carbon emissions. The return ratio is proportional to the value of the product; therefore it changes a lot depending on the sector and product. However the impact of this flow on total emissions is negligible since product returns are generally done via road transport and they are less than 0.05% of the total freight movement.

Increase forecast accuracy and better planning: As mentioned before, the biggest part of the emissions is coming from inter-continental lanes, especially from express shipments. Although the standard way of transport for most of the flows from Asia to Europe is sea freight, which is slow and less polluting, the volumes transported via air are still high because of the irregularities. One cause of this is stock-outs because of forecast errors and planning issues. There is a companywide policy to keep inventory levels at low levels. This increases the magnitude of the impact of the accuracy of the demand forecasts on the transport mode choice. The impact of forecast accuracy on emissions is expected to be high; therefore it can be considered as a promising alternative which will be investigated further on deep-dive scope.

Table 4.3 summarizes the above discussions and rates the feasibility, cost and estimated impact of the considered options on emissions on a 1 to 5 Likert scale. The options which are expected to have a bigger impact on reducing global emissions have bigger scores in “Estimated Impacts” column. The target lanes that each option could be applied to are listed under “Target Lanes” column. “Feasibility” dimension represents the rate of possibility and easiness to implement the listed
options, 5 meaning that it is quite feasible to implement or already in implementation. A score of 1 means that it is hard to implement or it may not be feasible in terms of required investments. More detailed comments on the implementation process of most promising options will be described in chapters 5, 6 and 7.

“Cost” dimension in Table 4.3 represents the magnitude of cost reduction that can be gained with the application of the mentioned option. Cost dimension with score 1 means that option promises very little cost savings or it is even more costly to implement such changes; therefore in those cases costs outperform benefits. Higher cost scores represent options which are expected to provide higher cost savings to the overall operations. The existing projects are represented with N/A since it is not necessary to further investigate such options; and the selected alternatives for the deep-dive analysis are indicated in red in the “Deep-dive” column.

Table 4.3: Summary of Reduction Options

<table>
<thead>
<tr>
<th>Summary of the Abatement Options</th>
<th>Estimated Impact (NTM)</th>
<th>Target Lane</th>
<th>Feasibility</th>
<th>Cost</th>
<th>Ongoing Projects</th>
<th>Deep-dive</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Moving production closer to the customers</td>
<td>5</td>
<td>Air/Road/Sea</td>
<td>1</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Due to economic reasons, production of several products is taking place in low-wage countries in far-east and it is not easy to alter this since the current situation is cost effective.</td>
</tr>
<tr>
<td>2 Eliminate or reduce empty kilometers / Pallet Banking</td>
<td>1</td>
<td>Road</td>
<td>4</td>
<td>5</td>
<td>Yes</td>
<td>N/A</td>
<td>The ratio of the empty distance travelled is low compared to the total distance travelled on road; hence the impact would be limited. Since there is an ongoing project on this issue it is not included in the deep-dive scope.</td>
</tr>
<tr>
<td>3 Restructuring supply chain and route optimization</td>
<td>3</td>
<td>Air/Road/Sea</td>
<td>5</td>
<td>Yes</td>
<td>N/A</td>
<td></td>
<td>Considering the fact that most of the flows are already optimum, additional impact of a study on this option would be medium. Because of the ongoing projects on this issue, it is not included in the deep-dive scope.</td>
</tr>
<tr>
<td>4 Packaging design initiatives</td>
<td>5</td>
<td>Air/Road/Sea</td>
<td>5</td>
<td>Yes</td>
<td>N/A</td>
<td></td>
<td>The sustainable packaging program is running. So it is not necessary to include it in the project scope.</td>
</tr>
<tr>
<td>5 Postponement - Late customization</td>
<td>3</td>
<td>Air/Road/Sea</td>
<td>5</td>
<td>Yes</td>
<td>N/A</td>
<td></td>
<td>Not applicable to all products. It requires initial investment but in the end results in reduced cost. However the impact on emissions is limited since the reduction in weight is not very significant.</td>
</tr>
<tr>
<td>6 Modal shifts and Intermodal transport / Co-Modal transport</td>
<td>4</td>
<td>Air/Road/Sea</td>
<td>3</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td>Modal shifts from more polluting modes to less polluting ones can reduce emissions significantly. However mode choice decision is market-driven for some products.</td>
</tr>
<tr>
<td>7 Vehicle type shift</td>
<td>1</td>
<td>Road</td>
<td>4</td>
<td>4</td>
<td>No</td>
<td></td>
<td>For sea, air and downstream-road, control of Philips over transport type is limited. For mainstream-road, additional impact of a transport type shift is low since the vehicles used are already in the group of less polluting ones. Since the impact is small, this option is not considered as a promising one.</td>
</tr>
<tr>
<td>8 Inventory Management</td>
<td>5</td>
<td>Air/Road/Sea</td>
<td>5</td>
<td>No</td>
<td>Yes</td>
<td></td>
<td>Inventory management has a direct impact on transport mode decision. However no study has been done before to investigate the trade-offs between emissions and inventory. Therefore it is included in the project scope.</td>
</tr>
</tbody>
</table>
As can be seen in Table 4.3, all options are qualitatively rated, according to their relative properties with respect to the other options. The following figure shows the options which are not already considered in ongoing projects, in order to identify the options with high scores.

As underlined in Figure 4.7, four options are selected for further elaboration: modal shifts and intermodal transport/co-modal transport, inventory management, increased load factor/adoption of more efficient order cycles and increasing forecast accuracy and better planning and analyzed further in Chapter 5, 6 and 7.
CHAPTER 5: ANALYSIS ON THE DEEP-DIVE SCOPE

This chapter is dedicated to the analysis of the selected scope. As stated in the problem approach, the impacts of the most promising abatement options on carbon footprint will be investigated further by using input data obtained for the deep-dive scope. Chapter begins with detailed information on the supply chain structure and operations planning; then the most promising options are discussed, except forecasting and inventory management which will be presented in Chapter 6 and 7.

5.1. Information on the Deep-dive Scope

In order to decide on a proper scope, several discussions are made with the employees from the “Green Logistics” team, which is formed by the representatives of the logistics related sustainability programs in each sector of Philips. In the end, the HID business unit from the Lighting sector was selected for two reasons:

- The impact of market related issues such as price erosions, competition etc. on transport decisions is less apparent in this business unit; therefore the inventory related tradeoffs can be observed more clearly.
- The supply chain is suitable for analysis since it includes several inter-continental lanes.

The scope is further narrowed down to the supply chain of the product group “MHN-TD” in Europe, since it is one of the products which is manufactured in the Far East and the transport quantities of this product are small enough to attain per shipment data which allows the daily shipments data to be downloaded from the central database. MHN-TD is a kind of lamp which is designed to meet the demanding requirements of professional sports lighting and floodlighting applications. Detailed information on the supply chain structure of this product group and operational planning is described in the sections 5.1.1 and 5.1.2.

5.1.1. Supply Chain Structure

The production of MHN-TD is outsourced to a supplier which is located in Shanghai, China. This supplier is a Make-to-order manufacturer and therefore it keeps very little outbound stock which only serves as a buffer. As soon as the production process is completed, products are sent to a consolidation center which is located close to the production facility to be combined with other products which are being shipped to same destinations. Then the products are shipped to one of the two regional distribution centers (RDC) which are located in Villeneuve St. Georges (VSG), France and Pila, Poland. There are also several local distribution centers (LDCs); however they do not keep stock of this product type; but just forward the orders from the customer to the RDCs. More detailed information about the sales regions assigned to each stock location and the visualization of the supply chain can be found in Appendix XI. Since the main aim of this study is to gain further insights on the relationship between emission and inventory management, main focus will be on the mainstream flows where replenishment takes place since stocks that are kept in RDCs play an important role.

5.1.2. Shipment Process Description

Planners in the central planning division, located in Turnhout, Belgium, create production and shipment orders on a weekly basis. Orders are based on the on-hand stock levels, forecasts and stock targets, aiming to reach targeted supply DRM (service level) while keeping inventory and transportation costs as low as possible. Order quantities are calculated as:
**Forecasted demand during the expected lead time + Safety stock + Backorders**

- Goods in transit - Current Inventory Level

Safety stocks are kept simply as the 14 day’s expected demand for both RDCs without any detailed calculation. This amount is determined based on past experience, does not depend on a particular reason; and it considers only the stochasticity of lead time. Since the variability of demand is not considered in safety stock calculations, it can be claimed that safety stocks might not be sufficient enough to cover all the components of stochasticity of this supply chain setting.

Shipments between the factory in Shanghai and the distribution centers in Europe can be made either via air or sea, with different transportation lead times and costs. The visualization of replenishment process can be seen in Figure 5.1.

![Figure 5.1: Inventory Replenishment process](image)

Air shipments to both stock points take less than one week; however sea transport lead time is different for each DC. Details on the shipment routes and vehicle types used during the process are given in Appendix XI. Transshipments are done between the two stock points in a reactive manner to respond to stock-outs or urgent situations, and the transshipment lead time is approximately three days. The costs structure associated with inventory and freight transportation will be explained later on.

### 5.1.3. Current Emissions Figures

For the purpose of understanding the structure of the current carbon footprint, several interviews are made with the employees within the business unit. The availability of detailed information at the people in charge of the processes allowed the application of NTM methodology in the most detailed level. Data sources are given in Table 5.1.

#### Table 5.1: Data Sources

<table>
<thead>
<tr>
<th>Data</th>
<th>Data Source</th>
<th>Transport flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin Country</td>
<td>Downloaded from SAP</td>
<td>All flows</td>
</tr>
<tr>
<td>Origin City</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Origin Postcode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination Country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination City</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination Postcode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle Type</td>
<td>Files from the DCs</td>
<td>Road transport</td>
</tr>
<tr>
<td></td>
<td>Information from LSPs</td>
<td>Sea transport</td>
</tr>
<tr>
<td></td>
<td>Information from LSPs</td>
<td>Air transport</td>
</tr>
<tr>
<td>Loading Degree</td>
<td>Files from the DCs</td>
<td>Road Mainstream</td>
</tr>
<tr>
<td></td>
<td>From one DC</td>
<td>Road Downstream</td>
</tr>
<tr>
<td></td>
<td>No data</td>
<td>Sea transport</td>
</tr>
<tr>
<td></td>
<td>No data</td>
<td>Air transport</td>
</tr>
<tr>
<td>Routing</td>
<td>Information from DCs</td>
<td>Road Mainstream</td>
</tr>
<tr>
<td></td>
<td>No data</td>
<td>Road Downstream</td>
</tr>
<tr>
<td></td>
<td>Information from LSPs</td>
<td>Air transport</td>
</tr>
<tr>
<td></td>
<td>Information from LSPs</td>
<td>Sea transport</td>
</tr>
<tr>
<td>Empty Returns</td>
<td>No data</td>
<td>All flows</td>
</tr>
</tbody>
</table>

Distance information was found using the database of Philips and TERRA tool. Data collected from the warehouses is highly reliable and includes per shipment information. However the reliability of the data collected from the service providers is questionable. They could not provide per shipment information but gave information on the most frequently used vehicle types on the requested lanes; emphasizing the unreliability of the data provided. In cases where no information is available, average values defined in NTM methodology are applied. TERRA tool is used for the
calculation processes, and the details of emission calculations can be seen in Appendix XIII. The results are given in Figure 5.2.

![Figure 5.2: Shares of transport means](image)

It can be seen from Figure 5.2 that majority of the emissions are originating from the transport movement on inter-continental lanes and the relative share of sea and air on emissions is close to each other, even though the number of shipments done via air is considerably small compared to sea shipments.

**Road Transport:**
Emissions resulting from the road transport of the selected product were analyzed in detail, and the results are summarized in Figure 5.3.

![Figure 5.3: Road Transport results](image)

It can be seen from Figure 5.3 that there are some lanes whose relative contribution to emissions is considerably higher than the others. The main reason for this is found to be the long distances that have to be travelled by trucks in order to meet customer demand in distant destinations. The lanes heading to Spain are examples for this and they account for approximately half of the emissions of the road transport. Therefore, if a distribution center is opened in Spain, approximately half of the emissions from road transport will be eliminated, which corresponds to approximately 4.5% of all the emissions for this product group. Even though this reduction option is also a promising one, it will not be investigated in detail since it is not included in the scope of the analysis.

The contribution of the flows originating from the local DCs on the carbon footprint is relatively small compared to the flows originating from the regional DCs, and the underlying reason is the shorter distances travelled. Besides, it is found that the contribution of lateral transshipments (inter-RDC shipments) to the total road emissions is 0.72 % which is negligibly small.
Sea and Air Transport:
Considering that there are only two lanes for both sea and air transport, the relative contribution of those lanes on total emissions are investigated, and found to be considerably high (ten times bigger) compared to road transport lanes. Since sea freight is considered to be one of the most environmentally friendly modes of transport, the focus will be on air transport in the discussion of the modal shift options. However, discussions on increasing loading degree by the adoption of more efficient order cycles are not relevant for sea and air transportation since container utilization is already close to optimum (more than 90%) for sea and there is no control over load factors in air shipments. The next section presents the findings about these options.

5.2. Impact of Abatement Options on the selected scope:
In Chapter 4, several abatement alternatives are extensively discussed and most promising options are selected. In this chapter two of them will be analyzed:
❖ Modal shifts and Intermodal transport
❖ Increasing loading degrees/ Adoption of more efficient Order Cycles

Modal shifts and Intermodal transport:
Analysis for the determination of most promising options revealed that this option is attractive for Philips because major reductions can be attained with alterations on few lanes. Thus, these lanes are the candidates for a possible change, because their relative contributions to global emissions are notable. However, another dimension that needs to be considered is the improvement potentials of these lanes. If the impact of a possible improvement of a candidate lane which contributes less is much bigger than the most contributing lanes, then it might be wise to continue analysis with the ones for which larger gains are expected.
For the selected scope, candidate lanes for improvement are the lanes of air transport. However changing the modality type is not possible for this case, since they are only used for expedited orders. Therefore, intermodal options which change increase the ratio of road transportation to air transportation for the shipments of expedited orders can be analyzed.
As mentioned before, the trend in air emissions is found to be due to the increase in the inter-continental emergency shipments. Since those kinds of deliveries are urgent deliveries, intermodal options that increases transport lead time significantly are not plausible alternatives. Therefore it is reasonable to consider only the airports in Europe for the arrival of the emergency shipments, since the final destination (RDC) will also be in Europe and the resulting delivery lead time will not increase too much.
Interviews with several planners on different sectors and a closer look at the transport data revealed that planners generally pick the airport which is closer to the final destination of the shipment. However significant reductions may be attained by selecting another airport which is farer from the final destination. The trade-offs in the airport selection process can be described as follows:
❖ Road and air distances will be altered, resulting in different emission values. The reduction in emissions can be considered as a benefit.
❖ On the other side, there will be a change in the air freight cost due to changes in the airports and the change in the transport lead time. Additional backorder costs can be faced because of the prolonged lead times. Those factors can form either cost or benefit, depending on their magnitude.
Air transport cost consists of five main components, four of which may differ depending on the airport chosen.

**Table 5.2: Cost components of air transport**

<table>
<thead>
<tr>
<th>Air transport cost components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight per kg</td>
</tr>
<tr>
<td>Airport terminal handling charges destination - per kg</td>
</tr>
<tr>
<td>Customs clearance destination - per shipment</td>
</tr>
<tr>
<td>Delivery to door per kg</td>
</tr>
<tr>
<td>Fuel surcharge (kg)</td>
</tr>
</tbody>
</table>

Except fuel charge, the values of the components will differ from lane to lane. Except delivery-to-door costs, other components are fixed and can be categorized in two groups which are: costs incurred per kg shipped (c_{kg}) and costs incurred per shipment (c_s).

Then, c_{kg} can be computed as the summation of the freight cost and airport terminal handling charges; and c_s is equal to customs clearance cost. Let c_d denote the delivery to door cost per kg which will change depending on the distance change of road transport.

Then change in the transport costs can be calculated as:

\[ \Delta c_t = (c_{kg}^{new} - c_{kg}^{old}) \times \text{Chargeable weight} + (c_s^{new} - c_s^{old}) + (c_d^{new} - c_d^{old}) \]

In addition, additional lead time will add additional holding cost for the products which can be calculated with the formula used by Philips as:

\[ c_h = \text{value} \times \text{CoC} \times \text{LT} \]

where value is the value of the product, CoC is the cost of capital value per day and LT is the lead time in days. The increase in the holding cost can be approximated as:

\[ \Delta c_h = (LT_r^{new} - LT_r^{old}) \times \text{value} \times \text{CoC} \]

where LT_r is the duration of road leg of the shipment. The difference in the durations of air shipments are assumed to be negligible since it is much smaller with respect to the change obtained by the additional road transport duration.

If the products are on backorder, this means delaying the final delivery by (LT_r^{new} - LT_r^{old}) units of time and this can be considered as a cost component which can be calculated as:

\[ \Delta c_b = b \times \text{Quantity of Backorder} \times (LT_r^{new} - LT_r^{old}) \]

where b stands for the received cost of postponing the final delivery by one unit of time.

Then the reduction in carbon emissions can be calculated as follows, assuming that the vehicle types in both air and road legs do not change:

\[ \Delta E = E_\text{Air} \times (d_{air}^{new} - d_{air}^{old}) + E_\text{Road} \times (d_{road}^{new} - d_{road}^{old}) \]

The change in the emission coefficients of road transport is due to the inclusion of terrain factor in calculations.

The cost gain (loss) can be calculated as follows:

\[ \delta = -c_e \times \Delta E + \Delta c_h + \Delta c_b + \Delta c_t \]

where c_e represents the monetary value of reducing 1 kg of emissions for the company.
An Excel tool is constructed, which tries to find out intermodal abatement options while trying to keep the increase in the transport lead time at controllable levels. The tool takes backorder cost, value of the product as the input and calculates the approximate changes in costs. This tool, which only considers European airports, can be used to direct attention on carbon emissions.

Using the abovementioned calculation method, associated cost and emission figures for several different intermodal options (landing on a different air port and increasing the road leg of the shipment) for Shanghai-VSG lane (which corresponds to approximately 33 percent of the total emissions) depicted in Figure 5.4, 5.5 and 5.6. Details for parameter estimates can be seen at Appendix XIII.

![Figure 5.4: Cost increase per product vs Emission reduction for intermodal options with a lead time increase of 1 day](image1)

![Figure 5.5: Cost increase per product vs Emission reduction for intermodal options with a lead time increase of 2 day](image2)
The names of each data point represent the associated airport of the intermodal lane option. Even though all possible reduction alternatives are plotted for lead time increase values of 1, 2 and 3 days which are thought to be reasonable increases for emergency shipments; some of the options are outperforming others by showing more reduction with least cost increase. In Figure 5.4, the outperforming lanes are via Germany (MHG, STR, FDH). Netherlands is another option with an increased cost. In both cases the reduction of carbon emissions per shipment is calculated to be around 3-5 percent. This reveals the fact that if products landed to Germany and transported to France via road, emissions per shipment can be reduced by 3-5 percent with an additional cost of 15 cent for the product group. In Figure 5.5, other airports in Germany (LEJ, HAM, BRE) can be used which in turn leads to 6-7 percent decrease in emissions with an additional cost of 20-25 cent per product. Emissions can be further decreased by using more distant airports like the ones in Poland (KTW, POZ, KRK, WRO) up to 10 percent by an increase of 40 cent in the total shipment cost as can be seen from Figure 5.6. Further decreases in emissions up to 18 percent is possible (via Finland, Lithuania) with prolonged lead times (6-7 days); and considering that 44 percent of the total emissions are coming from air shipments, up to 8 percent reduction of the overall emissions can be attained with this option.

**Increase load factor/ Adoption of more efficient Order Cycles:**

It was discovered in the interviews that the load factors of containers of sea transport are around 93%, which is a high ratio and difficult to improve. Besides the lack of information about load factors of air transport, the reduction opportunities are not under the control of Philips since the loading is done by the LSPs. Considering road transport, it is only possible to change the load factors for main stream flows. Hence, the data on deliveries from RDCs to LDCs was examined for 2009 shipments. Since the majority of the products of Philips are volume-critical, volume-based loading degrees were calculated. The results are depicted in Figure 5.7 and Figure 5.8. As can be seen from Figure 5.7, load factor values are condensed around the average value, which is calculated as 48.09 percent. In the shipment histogram, 20 percent of the shipments are below that level. The long tail of the load factor distribution indicates the improvability.
In order to spot any present relationship of load factors with destination or seasonality, sample comparison analysis is conducted using Statgraphics software. As a result, it was found that the loading degrees are significantly different for different destinations. However, the rate samples do not differ for different quarters, thus there is no seasonality. The details of the analysis can be seen in Appendix XIV.

Loading degree increase can be attained by possible changes in the delivery frequencies. It can be seen from the analysis in Appendix XIV (Figure XIV.2) that the load factors of Roosendaal and Northampton are significantly lower than the others. The expected increase in the loading degrees by changing weekly shipment numbers and resulting emission reductions can be plotted as:

The current shipment frequency is 5 shipments per week from Pila to these two destinations, and it is altered to 4 and 3 shipments per week. The percentages in Figure 5.9 indicate the reduction in emission, with respect to the current situation. Thus, as can be seen in the figure, up to 38.5 (32.6) percent reduction can be attained per shipment by changing the shipment frequency from 5 to 3 shipments per week for Northampton (Roosendaal). Further decreases in shipment frequency are not possible, considering the current situation, because of the maximum load restrictions. Even though the resulting impact on the total emission is expected to be less than 1 percent in this setting, up to 3-4 percent reduction might be attained in global emissions (since road corresponds to approximately 25 percent of all emissions as can be seen from Figure 2.1 and emission factor decreases around 14 percent) by increasing current load factor average by 10 percent globally.

To conclude, emission abatement potentials of a certain type of inter-modal transportation (air-road) and the potential effect of increasing loading degrees were discussed in this chapter. The remaining options, namely forecasting accuracy and inventory management, will be discussed in Chapters 6 and 7.
CHAPTER 6: EMISSION CONSTRAINED INVENTORY MANAGEMENT

Modeling and optimizing inventory replenishment decisions of such a system, even without taking logistical carbon emissions into account, is highly complex and state-dependent. Since the regular shipment lead time is longer than the review period, classical inventory models are not applicable to this problem. In addition, regular order lead times are stochastic and order crossing occurs from time to time. Considering that the optimal policy is state-dependent, dynamic programming could be used to model such a system. But dynamic programming model may not be solvable since it requires several state variables to be updated in each period. Hu et. al (2005) claims that dynamic programming model for the determination of optimum lateral transshipment quantities on a simpler setting is extremely difficult to deal with mathematically without simplifying assumptions. Even though using a policy similar to the Dual Index policies, which are proven to mimic the behavior of globally optimum and state-dependent policies found by dynamic programming for similar settings (Veeraraghavan and Wolf, 2003), it is not logical to base order quantities depending on inventory positions because the inventory position might be misleading since the transport lead time is quite long and variable. It is very difficult to keep track of the changes in the inventory levels during the transport lead time because during each review period emergency and lateral transshipments can be made depending on the actual on-hand inventory amount or regular orders that are placed earlier in time may arrive. The setting studied by Beyer and Ward (2000) is quite similar to the setting of this project. In their paper, they modeled the system using simulation and optimized it by creating an efficient search algorithm, which searches for the best solution among a set of computation results which satisfies the feasibility constraints.

In the next section of this chapter, an optimization model which shows the behavior of a simplified version of the problem is presented and findings are discussed. In section 6.2, the model is solved and sensitivity analyses are conducted. The model generates important insights on how the shape of the cost function is and how the emission constraints influence the behavior of the system at optimality.

6.1. Optimization Model

As mentioned in the previous section, order quantities are state-dependent which makes the optimization of such a system highly complex. Therefore, several simplifying assumptions, which are listed below, are made in order to make the model tractable, understandable and easily analyzable.

Assumptions:

- In the system under consideration, stochasticity of the regular order quantities stem from the deviation of weekly demand, forecasting errors and changing on-hand inventory levels when the orders are generated. Employing variable regular order quantities in the model increases the complexity significantly; because it requires the storage and update of all historical inventory levels, forecast and transport data. So as to simplify the model, regular shipment quantity \(Q\) is assumed to be constant for each period. Even though a policy like this is not being applied currently in the selected BU, using such a policy might have substantial benefits since it eliminates several operational complexities in the system. In addition, using a constant order quantity such as EOQ is quite reasonable in settings where the deviation in forecast is low such as the studied setting.
Complete pooling is assumed to satisfy the demand of both warehouses since the emergency cost is up to ten times higher than the transshipment costs. Lateral transshipments are done reactively at the end of the week, to satisfy the backorder of a warehouse if the inventory level of the other warehouse is positive. If the backorder of warehouse A is larger than the inventory level of warehouse B, then all available stock is sent to compensate part of the backorder and to keep the weekly service level as high as possible. If both warehouses are facing backorders, no transshipment is done.

Analysis made in Section 5.1.3 on the current carbon footprint revealed that contribution of inter-RDC transshipments to total carbon emission is relatively low compared to other flows; therefore they are neglected in order to simplify the system further.

The two RDCs are considered to be combined into one stock location, whose demand is independently and identically distributed over successive time periods with expected value $\mu$ which is equal to summation of the mean demands of the two locations ($\mu_1 + \mu_2$) and a standard deviation $\sigma$ which is the square root of the summation of the variances ($\sqrt{\sigma_1^2 + \sigma_2^2}$). The demand is assumed to be non-negative, since the amount of product returns is negligibly small when compared to regular demand and follow discretized version of the gamma distribution. Details on the demand distribution and the goodness of fit test results can be seen in Appendix V.

Orders are satisfied according to first come first served principle.

Emergency shipments are made reactively and happen instantaneously.

A constant emergency reorder level is assumed. If the inventory falls below this value after the realization of the demand, inventory level is increased up to this value, which corresponds to a backorder level that is assumed to be always less than or equal to zero.

Parameters and decision variables of the model are summarized below:

**Parameters**

- $N$ Set of periods indexed by $n=1...N$
- $I_n$ Beginning inventory level of each period $n$
- $D_n$ Demand occurred at period $n$
- $ESQ_n$ Emergency shipment quantity at period $n$
- $U$ Upper limit of inventory level allowed
- $h$ Holding cost per unit time
- $b$ Backorder cost for one unit of product
- $c_R$ Cost of shipping on unit of product with regular transport mode
- $c_E$ Cost of shipping on unit of product with emergency transport mode
- $c_{EM}$ Cost of emitting one kg of carbon dioxide
- $I^-$ Allowed backorder quantity
- $I^+$ On-hand quantity at the end of the period
- $ue_R$ Cost of shipping on unit of product with regular transport mode
- $ue_E$ Cost of shipping on unit of product with emergency transport mode
- $EM$ Kg of carbon dioxide emitted
- $SL$ Service Level
- $TSL$ Target Service Level
- $TBO$ Total Backorder Quantity

**Decision Variables**

- $Q$ Constant regular order quantity which arrives at the beginning of each period
Model Description:

The aim of the model is to gain insights on the shape of the cost function of the actual problem using a similar setting and understand how the optimal solution is affected from emission related parameters and decisions. In addition, the behavior of the system with a constant order quantity is of interest since application of such a policy might eliminate several operational complexities that are existent in globally dispersed supply chains. Since several simplifying assumptions are made, and the problem size is reduced considerably, the outcome of the model will have different performance values than the real life case; but the cost parameters are taken as the estimations of real life values, therefore the trade-offs in the model are assumed to represent the trade-offs that exist in the actual system.

Using the previously mentioned assumptions, the system can be modeled as a Markovian process. Since the weekly demand distribution is assumed to be independently distributed and the regular order quantity is assumed to be constant, the memoryless property which is necessary to model a system with Markov chain is assured. In Markovian processes, current status of the system is represented by state variables whose values take a finite or countable number of possible values. It is a random process with the property that the next state depends only on the current state and is independent of the past states.

In this setting, the cumulative quantity of products in two stock points is the variable which defines the states of the Markov chain. One could also consider having two state variables and representing the current status of the system with the inventory levels of the two warehouses. By this way the impact of lateral transshipments on total costs and emissions could also be covered and analyzed in the system. An example for this setting is presented and explained in Appendix XVI. However addition of each state variable introduces additional complexity to the solution of the problem by increasing the size of the matrix. Therefore the impact of lateral transshipments on costs and emissions is simply ignored in this model.

Let \( I_n \) be the inventory level at the beginning of period \( n \) then \((I_n); \ n \geq 0\) is a Markov chain on the state space \( SS=\{-1,0,1,...\} \). In order to simplify computations and restrict the state space to a finite value, upper and lower limits are defined to restrict the possible values of the beginning inventory levels. Upper inventory level can be described as the maximum quantity which the planner willing to store in the warehouse because of capacity issues and the quantities above this limit are assumed to be sold to spot market. Lower limit is restricted by the emergency shipment level since the inventory level will be increased to this level via emergency shipments if it falls below that level. Then the state space becomes \( SS = [U,E] \).

Beginning inventory level for each period is simply the ending inventory level of the previous period. Then we have the following recursive relationship:

\[
I_{(n+1)} = I_n + Q - D_n + ESQ_n
\]

where \( ESQ_n \) is the emergency shipment amount for that period and \( D_n \) is the the total demand of the two stock points.

The quantity of \( ESQ_n \) can be computed as:
Then the transition probabilities can be defined as:

\[
P_{ij} = P(I_{n+1} = j \mid I_n = i) = \begin{cases} 
P(D_n \leq i + Q - j) & \text{if } j = U \\
P(D_n = i + Q - j) & \text{if } E \leq j < U \\
P(D_n \geq i + Q - j) & \text{if } j = E \\
0 & \text{if } j > (i + Q) 
\end{cases}
\]

Steady state probabilities are defined as \( \pi_i = \lim_{n \to \infty} P(I_n = i) \) and \( \sum_i \pi_i = 1 \).

After computing steady state distribution, expected cost function becomes:

\[
E[C(Q,E)] = \sum_{i \in SS} \pi_i \cdot E[C_i(Q,E)]
\]

Value of \( E[C_i(Q,E)] \) for each possible beginning inventory level is calculated by summing up transportation, on-hand inventory, backorder and emission costs that are expected, if the period starts with the given initial inventory level. Thus,

\[
E[C_i(Q,E)] = c_R Q + c_E E[ESQ] + h E[I^+] + b E[I^-] + c_{EM} E[EM]
\]

where:

**Expected on-hand quantity:**

\[
E[I^+] = \int_0^{i+Q} (x - i - Q) f(x) \, dx
\]

**Expected backorder quantity:**

\[
E[I^-] = \int_{i+Q}^{i+Q-E} (x - i - Q) f(x) \, dx
\]

**Expected emergency shipment quantity:**

\[
E[ESQ] = \int_{i+Q-E}^{\infty} (x - i - Q) f(x) \, dx
\]

**Expected total emissions:**

\[
E[EM] = u_{EM} Q + u_{EM} E[ESQ]
\]

**Expected total backorder quantity:**

\[
E[TBO] = \sum_{i \in SS, i \leq 0} \pi_i \cdot i + \sum_{i \in SS, i < E} \pi_i \cdot E
\]

Then the optimal policy \((Q^*, E^*)\) is determined by solving the following problem to optimality:

\[
\min_{Q,E} \{ E[C(Q,E)] \mid SL \geq TSL, Q \geq 0, E \leq 0 \}
\]

where:

\[
SL = 1 - \left( \frac{E[TBO]}{\mu} \right)
\]

In order to clarify the structure of the Markov Chain model and its probability matrix, a simplified numerical example is generated for illustrative purposes and given in Appendix XVI with the explanations.
6.2. Solution of the Model:
Since solving the problem with its actual size might be very time consuming and computationally complex, a smaller problem size is studied since the main goal is mimicking the system behavior to gain insights from the analysis.

In order to solve the model, values of the parameters such as holding cost, backorder cost, unit emissions, transportation costs etc. were estimated. The details of the estimations can be found in Appendix XV. When unit emissions per product were calculated, it was seen that the resulting values are very close to the values calculated using the current methodology in Philips.

<table>
<thead>
<tr>
<th>Table 6.1: Calculated unit emission coefficients per product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pila Sea</td>
</tr>
<tr>
<td>NTM</td>
</tr>
<tr>
<td>Current Method</td>
</tr>
</tbody>
</table>

It can be seen from the table above that the coefficients calculated using the current method is lower than the coefficients calculated using the TERRA tool. However it is obvious that unit emission coefficients follow the same pattern when different transport modes are compared. Therefore the calculations that will be made in Chapter 6 and Chapter 7 can be considered as applicable for both calculation methodologies. But the analysis will be based on NTM method.

6.2.1. Solution Procedure
The model is solved using MATLAB Optimization module. The steady state probabilities are determined by computing the normalized eigenvector of the matrix P for the eigenvalue one:

\[
\pi = P^T \pi, \quad \pi = (\pi_i)_{i\in\mathbb{S}}
\]

where \(P = (P_{ij})_{i,j} \in \mathbb{S}^2\) denotes the matrix of the transition probabilities.

6.2.2. Characteristics of the Cost Function
In the initial problem definition, the cost parameters were estimated as given in the table below:

<table>
<thead>
<tr>
<th>Table 6.2: Parameter Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter values:</td>
</tr>
<tr>
<td>Emergency shipment cost (euros)</td>
</tr>
<tr>
<td>Regular shipment cost (euros)</td>
</tr>
<tr>
<td>Holding cost (euros)</td>
</tr>
<tr>
<td>Backorder cost (euros)</td>
</tr>
<tr>
<td>Unit Emissions Air (kg)</td>
</tr>
<tr>
<td>Unit Emissions Sea (kg)</td>
</tr>
<tr>
<td>Emission cost per kg CO2 (euros)</td>
</tr>
</tbody>
</table>

Before continuing with further analysis, it can be seen from the cost values given in table above that the tradeoffs that exist on a typical inventory management problem will not be apparent in this setting, considering the fact that inventory holding cost is considerably small compared to backorder and emergency shipment cost values. Therefore, the system will try to avoid backorders and emergency shipments by keeping sufficient inventory to satisfy demand and absorb possible variations in demand to reach targeted service levels. The cost value is not expected to increase much when stock levels are increased via increasing the regular order quantity. The shape of the objective function which can be seen from Figure 6.1 supports the above mentioned arguments.
Figure 6.1 is a three dimensional visualization of the cost function where Q values are plotted in X axis, E values are plotted in Y axis and the corresponding objective function (cost) is shown which corresponds to the values in the Z axis. The dark blue regions represent the areas where the objective function value is minimized. The corresponding objective function value of each color on the graph is indicated on the bar given nearby the figure.

It can be seen from Figure 6.1 that the minimum cost is observed where Q value is close to 16 (where the mean demand is taken as 16.78 and the standard deviation is as 8.87) and an E value close to zero. For the Q values that are bigger than the optimal value, the increase in the objective function is minor and this results in a flatter shape; however there is a steep increase if Q value is less than the optimal value. The underlying reason for this behavior is that, each Q value less than the optimal value, increases the probability of stock-out and in turn triggers backorders and emergency deliveries whose costs are estimated to be very high compared to the holding cost value. The steepness of the curve decreases when the Q value gets even smaller because of the distribution of the demand since the probability of demand values being greater than the specified order quantity gets smaller in that direction.

Additionally, it was seen via additional analyses that the shape of the cost function depends on neither the defined upper limits nor the variability of demand; however it only changes when cost coefficients are altered. For optimality, the model tries to increase the regular order quantity and creates a buffer stock which can be considered to be similar to keeping more safety stocks to keep up with demand variability. Thus, increases in the variability of the demand only shift the optimal point to the direction of increasing Q values.

6.2.3. Optimization and Sensitivity Analysis

Optimum Q and E values are found to be equal to 17 and -6 consecutively with a service level of 97.8% and emission value of 0.1853. It was seen that the resulting objective function value lies in the minimum value region of the cost function graph. A constant regular order quantity of 17 is quite reasonable since it is close to the mean weekly demand and slightly higher to absorb the variability
of demand. A small value of E is also logical to since backorders under this point may cause lower service levels than the targeted one, which was 0.95 in this case.

In order to get an insight about the impact of emissions on the behavior of the system, a small scale sensitivity analysis is performed in which emission cost values are altered. Minor changes in the emission prices are found to be not influencing the optimal solution since the change it creates is negligible compared to other cost components. When the carbon prices are set around 7 times higher than the current prices in EU ETS which corresponds to the value 0.1 in this case, the emission cost starts to influence the optimal solution by shifting the optimal value to a point with greater Q, smaller E values, as can be seen from Figure 6.2 and Figure 6.3.

As the emission cost increases, regular order quantity also increases to shift the shipped amount to regular from emergency shipments. With the decrease in the expected emergency shipments, the model pushes E level upwards to increase the service level. The rate of increase in E is higher than the rate of increase in Q since emergency costs are relatively higher.

Besides, other scenario analyses were conducted which revealed the following points:

- Increase in the target service level triggers more emergency shipments and thus increases the emissions.
- At the optimal solution, target service level constraint is not binding for values lower than 0.98.
- When backorder cost is increased, E value rises slightly in order to decrease the total expected backorder cost.
- If the emission is constrained, Q is increased to decrease the ratio of emergency shipments. Thus the system tries to decrease E, however the target service level constraint forces this value upwards and as a result its value does not change and the service level constraint becomes binding.

To conclude, Markovian model provides useful insights on how the shape of the objective function looks like, what the constant regular order quantity should be and how the system behaves at certain conditions. In order to see the impact of other factors such as lead time variability, lateral transshipments, forecast errors etc. a deeper look to the system is necessary. Therefore a discrete event simulation model which has an enriched content is presented in Chapter 7.

![Change in Q with different emission cost values](image1)

![Change in E with different emission cost values](image2)

**Figure 6.2: Q vs. Emission Cost**

**Figure 6.3: E vs. Emission Cost**
CHAPTER 7: SIMULATION MODEL

As explained before, the Markov chain model was not sufficient to reflect the behavior and all the tradeoffs of the system on hand, the effect of forecast errors, the stochasticity caused by highly varying lead times and calculation of regular order quantities based on forecasts etc. which are the essential parts of the considered supply chain. For this reason, a discrete event simulation model was built which allows making more detailed analyses on weekly shipment order decisions, aiming to obtain noteworthy implications about the behavior of such systems. The model was built in Arena 7.0, which also provides optimization using its embedded OptQuest tool. This chapter explains this simulation model, its assumptions, optimization, scenario and sensitivity analyses; and gives practical insights to Philips about the impact of the previously selected promising abatement options, namely inventory management and forecast accuracy, on logistical carbon emissions.

7.1. Model Assumptions

Although the modeling of such complex systems with simulation is deemed to be more realistic than other possible mathematical models because of the possibility of mimicking the behavior of real life behavior using decision rules that are parallel to the actual rules (Banks et al., 2009), it still requires preliminary assumptions to make the model understandable and analyzable. The assumptions made for this model are listed below:

- The length of the review cycle is taken as one week since it is the current application in the company for this product group.
- Demand is assumed to be continuous, contrary to the Markov Chain model, and also non-negative. Although the quantities should be integers, solutions are found using continuous variables.
- Demand is realized at the end of the week, after all regular, lateral and emergency shipments are received at the warehouse.
- The replenishment decisions are made based on forecasts since it is the actual calculation method that is currently applied in Philips as described in section 5.1.2. Regular orders are given based on the forecasts of the upcoming 7 and 5 weeks for Pila and VSG consecutively. Although currently in Philips monthly forecasts are divided by 4 to obtain weekly forecasts, separate forecasts are generated in the simulation model for the ease of computation. Thus, regular order quantity formula can be stated as: Regular order quantity = Forecasts during average lead time + Safety stock – Goods-in-transit – Inventory Level – Emergency shipment of that week + Backorder.
- Forecast data were available only for five months because of a change in the database systems, which made it impossible to obtain unbiased fitting of the data to the correct distribution. Silver et al. (1998) recommends the usage of normal distribution for forecast errors. Thus, forecast errors were assumed to follow a truncated normal distribution, where truncation was necessary due to the logic applied in the simulation model to prevent negative demand values. Making an educated guess relying on the interviews made with the planners and the availability manager of this product group, coefficient of variation for the forecast error, which is the ratio of the standard deviation of forecast error to the mean demand, was assumed to be 0.45 for both Pila and VSG, since the variability in this product group is classified as medium variability within the firm. However, solutions for other possible coefficient of variation values were also obtained for sensitivity analysis.
Forecasts are assumed to be unbiased.

It was confirmed by the interviews that there is generally enough buffer stock at the outbound of the factory at Shanghai, China to satisfy emergency shipments. Besides, the standard deviation of the production lead time is explained to be low and its mean is assumed to be 4 weeks. For these reasons, the simulation model only considers shipment decisions, excluding the production. In other words, every week (review) the decisions about how much to ship via air, how much to ship via sea and how much to transfer from one warehouse to the other are given. This structure of the model implies two assumptions:

- **Production lead time is constant and equal to 4 weeks for both Pila and VSG.**
- Since very limited historical forecast information exists, it was not possible to estimate how much change occurs between the forecasts made before and after the production. Thus, **forecasts made 11 (9) weeks before the actualization of the demand is assumed to be equal to the forecasts made 7 (5) weeks before for Pila (VSG).**

Emergency shipments are done proactively for each warehouse, anticipating a possible stock-out which cannot be supplied from the other warehouse. The shipment is generally received within that week, thus the lead time for the emergency shipments is assumed to be 5 days, without loss of generality.

Complete pooling is assumed to satisfy the demand of both warehouses. Lateral transshipments are done reactively at the end of the week, to satisfy the backorder of a warehouse if the inventory level of the other warehouse is positive. If the backorder of warehouse A is larger than the inventory level of warehouse B, then all available stock is sent to compensate part of the backorder and to keep the weekly service level as high as possible. If both warehouses are facing backorders, no transshipment is done. In other words, reorder level for lateral transshipments is assumed to be zero.

Holding, backorder and transshipment costs for both warehouses were assumed to be identical.

### 7.2. Explanation of the Model

The structure, variables and attributes of the simulation model are given in Appendix XVII together with the explanation of the underlying working logic behind the simulation model.

The time unit is taken as one day and the review period lasts 7 time units (1 week). The sequence of events in each review period can be listed as follows:

- At the beginning of each review period; inventory amounts, goods in transit and demand forecasts are checked and emergency shipments orders are given depending on the anticipated backorders. Then, regular orders are generated based on the forecasted demand during the expected regular transport lead time.

- The regular and emergency orders from previous review cycles are received within the review cycle.

- Finally, demand is realized; backorders, on-hand inventory, emission, cost and service level statistics are calculated by multiplying associated quantities with the parameters that are calculated per unit of product.

These processes can be observed in the model picture provided in Appendix XVII. In order to obtain representative statistics, the model was run for 50 years (18200 days) using initial parameter values which are found adequate to represent the steady-state behavior of the system.
Calculation of the Input Parameters:
Cost and emission coefficients of regular and emergency orders based on NTM, inventory holding and backorder costs, and demand distributions were already calculated for the Markov Chain model in Appendix XV. However, the simulation model requires additional parameters and estimates for initial values; such as lateral transshipment costs and emissions, sea shipment lead time distributions, safety stock levels and forecast error distribution. Calculation procedure of these parameters is explained in Appendix XVIII.

7.3. Verification and Validation
Verification is necessary to determine whether a conceptual model is correctly represented by the simulation software. Verification involves debugging the simulation code, and interpretation of the outputs to determine if the model functions as it should (Law and Kelton, 1991).

In our case, verification is possible using “Run Controller” console of Arena. The flow of entities and accuracy of the decisions are tested for all the decision rules that are defined in the system. As an example for this, a randomly chosen 1-week period (namely, from day 700 to 707), whose flow of operations is traced, is explained and a summary table of quantities is given in Appendix XIX. These figures verify that inventory balance equations are satisfied and emergency, lateral and regular order quantities are given as expected.

Besides, another verification method can be to indicate the overall balance of the goods entered and left the system. For that purpose, the following table is obtained from a short run (for 182 days) of the simulation.

Table 7.1: Verification Example

<table>
<thead>
<tr>
<th>Initial Inv.</th>
<th>Goods arrived</th>
<th>Goods delivered + Final State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Inv.</td>
<td>Total Demand</td>
<td>Total Demand</td>
</tr>
<tr>
<td>Pila</td>
<td>Pila</td>
<td>VSG</td>
</tr>
<tr>
<td>VSG</td>
<td>Pila</td>
<td>VSG</td>
</tr>
<tr>
<td>12000</td>
<td>265780</td>
<td>139470</td>
</tr>
<tr>
<td>15000</td>
<td>267450</td>
<td>15473</td>
</tr>
<tr>
<td>Initial state + Goods arrived</td>
<td>Ending Inv. Pila</td>
<td>Ending Inv. VSG</td>
</tr>
<tr>
<td>439480</td>
<td>608</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.1 shows that the total quantity of goods arrived to Pila and VSG with the preset initial inventory parameters together, are approximately equal to the total demand satisfied from both warehouses with the total ending inventory, when the ending backorder amount is subtracted. The small difference stems from the rounding errors of Arena’s representation via the powers of ten. The simulation output for the data presented in Table 7.1 can be found in Appendix XX.

Validation is done for determining whether a built model is an accurate representation of the actual system. In other words, validation is the confirmation of the model’s results via the information obtained from real-life. In our case, validation is done at two points:

- Comparison of the outputs of the simulation with actual statistics,
- Interpretation of the behavior of the system in specific situations, i.e. checking if the model’s behavior is parallel to real-life expectations (Law and Kelton, 1991).

For the first purpose, means and standard deviations of the demands for both warehouses were found to be approximate to the actual means and standard deviations as given in Table 7.2.

Table 7.2: Actual vs. Simulation Demand Statistics

<table>
<thead>
<tr>
<th>Demand of Pila</th>
<th>Demand of VSG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
</tr>
<tr>
<td>Mean</td>
<td>5665</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>2942</td>
</tr>
</tbody>
</table>

44
More importantly, service levels of Pila and VSG were calculated in the simulation model to be 96.08% and 95.92% consecutively. Actual average service level for the first 43 weeks of 2009, including both warehouses, was also 96.08%. The ratios of shipment quantities in the simulation are compared to the actual ratios, as given in Figure 7.1. The simulation output used for this figure can be found in Appendix X. It can be seen that lateral shipment percentage in the simulation is close to the actual value, which also supports the proximity of the service levels.

For the second purpose, two variables (safety stock levels and standard deviations of the forecast errors) were altered to observe the changes in the resulting costs, emissions and service levels. When the safety stock levels are doubled; service levels increased to a level over 99.8% because of the considerable decrease in the non-stock-out probability, average costs per week decreased by 21.9% and emissions dropped by 58.9% since the amount of emergency shipments decreased significantly. Also, when the standard deviation of the forecast error was doubled; emission value increased by 6.1% and the average cost increased by 10.6% because of the increase in the number of emergency shipments, and service level decreased slightly. Thus, it can be concluded from the above statistics that the system works as expected and it responds to the changes as it should in real life.

To sum up, it can be said that the simulation model works correctly and is a representative of the actual system.

7.4. Tradeoff between Inventory and Emissions
As explained before, this model aims to pinpoint the effect of inventory management and forecast accuracy over carbon emissions. It was already shown that the biggest contribution to emissions was made by air shipments, which were caused by irregularities and stock-outs. Since the primary variable affecting non-stock-out probability is the safety stock, it is also expected to decrease the ratio of emergency shipments and therefore emissions. In order to analyze the effects of different safety stock levels on service levels, costs and emissions; the simulation model was executed for seven incremental $\alpha$ values which correspond to fill rate coefficients of particular safety stock levels. “$\alpha$” parameter can be considered as the control variable whose value was changed in the interval starting from 85% to 97.5%, with an increment of 2.5% and several statistics were recorded. Resulting service levels for corresponding safety stocks are depicted in Figure 7.2. The bigger dots at the figures represent the current situation, which corresponds to the safety stock levels when $\alpha$ is taken as 0.9.
Figure 7.2: Service level vs. Safety Stock

Figure 7.2 shows that resulting service levels increase as the safety stocks increases. However, after specific levels, the slope decreases significantly and further increases in the safety stock results in minor increases in the resulting service levels. The underlying reason behind this behavior is that the marginal contribution of additional safety stock decreases because of high inventory levels, by absorbing the risk of stock-outs.

Also, resulting average lateral transshipment and emergency shipment amounts for each warehouse with respect to average inventory levels are found to be as follows:

![Emergency and Lateral Transshipments for Pila](image)

![Emergency and Lateral Transshipments for VSG](image)

As expected, average emergency and lateral shipments decrease as the safety stock increases. It is worthy to note that a decrease of 80.5% (85.8%) in the average emergency shipments can be obtained for Pila (VSG) with an increase of 25% (43.5%) in the average inventory levels.

Resulting emission levels for the “α” values corresponding to the same safety stock values are found as given in Figure 7.5.
Figure 7.5 depicts the decrease in emissions as the safety stock increases. The slope of the graph increases after a 92.5%, i.e. the reduction amount in emissions decreases as the safety stock increases. However, it is also necessary to observe the changes in total cost for these different fill rate values; therefore it is depicted in Figure 7.6.

The shape of the cost function and the tradeoff between costs and inventory is clearly seen from Figure 7.6. The total cost decreases as the safety stock level increases since the holding cost is relatively low compared to the emergency shipment cost; however, after some point, holding cost of the additional inventory overtakes the emergency shipment costs; therefore total cost starts to rise again. The minimum cost is observed around the fill rate of 0.95 which corresponds to a service level of around 99.3%. Therefore it can be concluded that increasing target fill rate to 0.95 will reduce the emissions by 47.2% and decrease the costs around 13.6% and further improvements may be possible since this point might represent suboptimal safety stock levels for the two warehouses. This tradeoff structure indicates an opportunity for optimization since the shape of the cost function indicates the existence of a global minimum. Note that emission is also one of the cost components.

Besides the determination of safety stock levels, emergency shipment decisions is also a part of inventory management and its calculation method can significantly affect the costs. Currently in Philips, emergency shipment decisions are given mostly proactively and quantities are calculated as the anticipated required (backorder) amount for the upcoming period. A different approach is adopted by Beyer and Ward (2000). In their study, emergency shipments are given in order to make the non-stock-out probability greater than or equal to the target service level for that week. Considering the high variations of forecast errors, this might be reasonable since ordering the expected backorder amount by an emergency shipment is only sufficient when the actual demand is less than or equal to the forecasted demand. Thus, this condition corresponds to a non-stock-out probability of only 50%, under the assumption that that week’s forecast error is normally distributed. However, in our case it is not possible to obtain different distributions for every week, thus a general emergency buffer stock value can be calculated in order to utilize commonly for each week. A common amount can also be suitable because it behaves as a weekly safety stock level which ensures non-stock-out probability; it is also suitable for seeing overall affects on the system and for optimization. Thus, the optimization can be done over safety stocks and emergency buffer stocks.

### 7.5. Optimization Using OptQuest

In the previous section, it was argued that optimization is possible over safety stock and emergency buffer stock values. However, continuous optimization is highly time-consuming to perform in
OptQuest, since OptQuest executes the simulation for every possible value combination. Although the tool utilizes algorithms such as tabu search, scatter search, neural networks, etc. (Niranjan, 2005); even obtaining integer (discrete) solutions is very difficult. The range of the decision variables that should be searched is large; thus for the chosen ranges of the decision variables in our case, total number of integer combinations are $7.5 \times 10^{16}$. For this, iterative search approaches are adopted in order to reduce the length of uncertainty with iterations and find the optimal solution.

Since plotting the shape of the cost function on the previously determined four decision variables (a five-dimensional graph) is not possible; it was anticipated that the cost graph in Figure 7.6 as function of $\alpha$, the control variable which determines the safety stocks, is a representative of the system as a whole, considering that the decision variables are safety stocks or behave as safety stocks. This anticipation was supported by several runs of the simulation model, the total cost function showed convexity for all decision variables when the other three decision variables were kept constant at their reasonable levels as control variables. Assuming a convex cost function for the multidimensional optimization whose results are presented in Table 7.3, a near-optimal solution is obtained using discrete steps of 100, then these values were used as suggested values and the optimization is run again using discrete steps of 10. Finally, new near-optimal parameters were again used as the suggested values and the optimal solution is found using discrete steps of 1 (integer solution).

As the optimization problem, total cost of the system is minimized without any constraints since optimization with constraints was not possible due to the logic embedded in the OptQuest tool, which requires the constraints to be represented as a combination of decision variables and constants. Emission is added as a cost component instead of a constraint because previous tradeoff analysis showed that even suboptimal alternatives for safety stock can decrease the emission more than 40% (see Figure 7.6). Thus, if an emission constraint was to be employed to decrease the total emission by 10% with respect to the current situation, it would be easily satisfied and far from binding. Optimization was solved as indicated; the optimal solution and resulting statistics are given in Table 7.3, for the comparison with the current situation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Current Situation</th>
<th>Optimal Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.V.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pila Safety Stock</td>
<td>9951</td>
<td>13604</td>
</tr>
<tr>
<td>VSG Safety Stock</td>
<td>21068</td>
<td>27324</td>
</tr>
<tr>
<td>Pila Emergency Buffer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VSG Emergency Buffer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>α Value for Pila</td>
<td>0.9</td>
<td>≈0.95</td>
</tr>
<tr>
<td>α Value for VSG</td>
<td>0.9</td>
<td>≈0.94</td>
</tr>
<tr>
<td>Pila Service Level</td>
<td>96.08%</td>
<td>99.18%</td>
</tr>
<tr>
<td>VSG Service Level</td>
<td>95.92%</td>
<td>98.82%</td>
</tr>
<tr>
<td>Pila Avg. Inventory</td>
<td>15052</td>
<td>17814</td>
</tr>
<tr>
<td>VSG Avg. Inventory</td>
<td>21154</td>
<td>28075</td>
</tr>
<tr>
<td>Average Cost</td>
<td>670.07</td>
<td>574.04</td>
</tr>
<tr>
<td>Average Emission</td>
<td>398.57</td>
<td>235.43</td>
</tr>
<tr>
<td>Total Emergency</td>
<td>622.74</td>
<td>177.554</td>
</tr>
<tr>
<td>Total Lateral</td>
<td>1016.37</td>
<td>763.91</td>
</tr>
<tr>
<td>Total Backorder</td>
<td>652.91</td>
<td>165.786</td>
</tr>
</tbody>
</table>
As Table 7.3 indicates, average emission decreased by 40.93% at the optimal solution, also with a decrease of 14.33% in the average cost. This result stems from the decrease in the amount of emergency shipments, which dropped significantly. Although optimal solution suggests 36.71% (29.69%) increase in the safety stock of Pila (VSG), it suggests no additional emergency buffer to order in addition to the anticipated emergency shipment quantity. Also, the decrease in the total backorders resulted in a notable increase in the service levels.

As explained previously, emissions drop significantly and any possible emission constraint would be quite easily satisfied. This might be because the impact of the cost of emergency shipments’ emissions is minor compared to the impact of emergency shipments’ costs. At the optimal solution, total emission cost was found to be 0.06% of the total cost of the system. Thus, the optimization is lead by the tradeoff between costs of holding inventory and ordering emergency shipments. For the emission constraint to become binding and change the optimal solution, emission coefficients or the cost coefficient of the emission should be very high to have a role in the tradeoff. In order to investigate this issue further, a sensitivity analysis is made for different emission cost values and presented in section 7.7. However, the optimal solution suggests notable increases in the safety stock levels. The applicability of extreme changes in inventory management is arguable, thus applicable changes should also be noted. This matter will be discussed on the next section.

7.6. Scenario Analyses
Scenario analysis is conducted using two situations: the base case and the optimal solution. Influences of lower (than optimal) safety stock levels and the comparison of reactive and proactive emergency shipments are done using the base case. However the impact of an emission constraint is observed over the optimal solution. Also, the option of employing fixed order quantities is evaluated considering both cases.

Safety Stocks:
As mentioned before, currently held safety stocks correspond to the expected demand of 14 days. However, optimal solution suggested relatively higher safety stock levels, which approximately correspond to the demand of 19 days. Since the handling of such high inventory levels might be a problem due to capacity restrictions and the optimal solution may not be applicable, the cost and emission effects of lower safety stock levels were also evaluated by the simulation model. Following table shows different safety stock levels and the incremental reductions in cost and emission.

<table>
<thead>
<tr>
<th>Safety Stock Days</th>
<th>Pila Safety Stock</th>
<th>VSG Safety Stock</th>
<th>Average Emission</th>
<th>Average Cost</th>
<th>% Decrease in Emission</th>
<th>% Difference in Emission</th>
<th>% Decrease in Cost</th>
<th>% Difference Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 days</td>
<td>10662</td>
<td>22573</td>
<td>364,31</td>
<td>650,2</td>
<td>8,60%</td>
<td>8,60%</td>
<td>2,97%</td>
<td>2,97%</td>
</tr>
<tr>
<td>15 days</td>
<td>11373</td>
<td>24078</td>
<td>378,57</td>
<td>670,07</td>
<td>9,87%</td>
<td>9,87%</td>
<td>3,76%</td>
<td>3,76%</td>
</tr>
<tr>
<td>16 days</td>
<td>12083</td>
<td>25583</td>
<td>413,81</td>
<td>584,47</td>
<td>16,36%</td>
<td>16,36%</td>
<td>2,97%</td>
<td>2,97%</td>
</tr>
<tr>
<td>17 days</td>
<td>12794</td>
<td>27087</td>
<td>449,09</td>
<td>578,78</td>
<td>18,77%</td>
<td>18,77%</td>
<td>5,92%</td>
<td>5,92%</td>
</tr>
<tr>
<td>18 days</td>
<td>13505</td>
<td>28600</td>
<td>484,35</td>
<td>572,99</td>
<td>20,32%</td>
<td>20,32%</td>
<td>9,59%</td>
<td>9,59%</td>
</tr>
</tbody>
</table>

Table 7.4 shows the decrease in cost and emission for each one-day’s-expected-demand increase in the safety stocks. It can be seen that an extreme decrease occur when increasing the safety stock from 15 days’ demand to 16. This might be because of the shape of the demand distribution generated by Arena, which may cause a sudden decrease in the probability of requiring emergency shipments to satisfy the demand at that threshold.
Thus, it can be concluded that at the safety stock level of 16 days’ expected demand, the biggest improvement with minimum change can be obtained.

**Reactive vs. Proactive Emergency Shipments:**

Optimization of the model which used proactive emergency shipments yielded a result where the safety stocks are very high and the emergency buffer of the proactive shipments were 0, which can be interpreted such that the model tries to make as few emergency shipments as possible. Also, although the proactively anticipated backorder is ordered as an emergency shipment, actualization forecast errors at the end of the week might result in unnecessarily higher or lower amount of shipped goods. Therefore in this case, extra unanticipated backorder or holding costs occur. Because of the abovementioned reasons, “reactive” emergency shipments might be reasonable to cut unnecessary costs, only by consenting up to one-week backordering of emergency shipment quantities. In order to depict this tradeoff and to observe the behavior of the system in the reactive setting, the simulation model is modified and the new model is verified. The structural difference of the reactive model with respect to the previous proactive model is given in Appendix X. The simulation is executed for different safety stock levels ($\alpha$ ranging from 0.85 to 0.975) which were determined in Section 5.4.3, and the resulting cost vs. emission graph, including the previously calculated proactive option, is as follows:

![Figure 7.7: Comparison of Proactive and Reactive Models](image)

It is visible in the Figure 7.7 that reactive emergency shipments are more economical in this setting. Although emergency shipments are considered as backordered for the next week, eliminating the cost effect of forecast error deviation results in lower costs. Similar emissions are observed for high safety stock levels, but it is lower if less safety stocks are held. Also, it is worthy to note that resulting service levels for each safety stock level are very close for proactive and reactive cases. For example, for $\alpha=0.95$, resulting service levels are found as 99.3% and 99.23% for proactive and reactive cases consecutively.

Thus, it can be concluded that, if emergency shipments were given reactively instead of a proactive manner, resulting service levels would be the same and emissions would be similar or even lower, however the cost would decrease by around 15-20%.
Emission Constraint:
In order to observe the cost and inventory impact of an emission constraint; an optimization problem was solved, aiming a 10% reduction in the emission value which was previously found in the optimal solution. This would require the average emission to be less than or equal to 211.9 (90%*235.43). The results of the emission-constrained-optimization suggested a 7% increase in the safety stock of Pila, and a 2.9% increase in the safety stock of VSG. However, to realize the emission target, total cost deviated from the optimal solution, increasing by 0.7% to 578.01.

Economic Order Quantity:
Currently, as explained before, the decisions on regular order quantities are done considering the forecasts of the upcoming periods. However, fixed order quantities can also be employed, which might be reasonable in this setting since the forecast accuracy is considerably low. Besides, this option eliminates the complexity in shipment decisions significantly. The optimal economic order quantities were calculated for both warehouses using OptQuest; the resulting figures are represented in Table 7.5, and the values for the current situation and the previously found optimal solution are presented for comparison.

Table 7.5: Comparison of the EOQ solution

<table>
<thead>
<tr>
<th>Setting</th>
<th>Average Emission</th>
<th>Average Cost</th>
<th>Average Emergency Sh.</th>
<th>Pila Service Level</th>
<th>VSG Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Situation</td>
<td>398,57</td>
<td>670,07</td>
<td>622,74</td>
<td>96,08%</td>
<td>95,92%</td>
</tr>
<tr>
<td>Optimal Solution with orders based on forecasts</td>
<td>235,43</td>
<td>584,40</td>
<td>177,55</td>
<td>99,18%</td>
<td>98,82%</td>
</tr>
<tr>
<td>Optimal Solution with economic order quantity</td>
<td>452,72</td>
<td>683,66</td>
<td>788,58</td>
<td>97,73%</td>
<td>96,96%</td>
</tr>
</tbody>
</table>

As can be seen from Table 7.5, economic order quantities result in an increase in both emission and cost, compared to the other two situations. This difference stems from the increased amount of goods carried via emergency shipments. Although the optimal solution suggests keeping higher safety stocks with respect to the current situation, the economic order quantities do not suffice to satisfy the highly variable demand. When the solution is compared with the previous optimal solution where orders are given based on the forecasts, it can be concluded that forecasts are still effective to anticipate the actual demand despite the high variability.

7.7. Sensitivity Analysis
In order to observe the change in the optimal solution with respect to the changes in the input parameters and investigate one of the promising options, namely forecasting accuracy, sensitivity analysis is performed for different values of the coefficient of variation of the forecast errors, holding cost, backorder cost and emission cost. The results are summarized below.

Forecast errors:
One of the main goals of this simulation model is to investigate the impact of forecasting on emissions. Thus, to observe the behavior of the emissions with respect to different standard deviation values of the forecast error, the Coefficient of Variation (COV) values is altered from to 0.25 and 1.25. As mentioned before, COV of the current system is assumed to be 0.45, which was decided by an educated guess resulting from interviews made with professionals. Thus, it is also important to see how different COV affect the results. Emission values, emergency shipment, lateral transshipment and backorder quantities in Figures 7.8 and 7.9 were obtained from the solutions.
Figures 7.8 and 7.9 depict the increase in the average backorder, lateral transshipment and emergency shipment values and the average emission of the system, as the standard deviation of the forecast error distribution increases. The results are as expected since the high deviation of the demand from expected values result in more backorders and additional buffer shipments which will increase the emissions and therefore the total cost. However the rate of increase after point 0.5 is considerably higher than the rate before this point as can be seen from the shape of the emission function in Figure 7.9. Therefore it is beneficial for the company to keep the COV values lower than 0.5 so as to avoid steep increases in emissions.

**Holding Cost:**
Holding cost coefficient was calculated to be very low compared to backorder and emergency shipment cost parameters. Therefore, its value is altered from the base value (estimated parameter) to its threefold. The change in optimal safety stock values and corresponding average emission and average total cost figures are given in Figure 7.10 and Table 7.6.

**Backorder Cost:**
The effect of the backorder cost on the optimal solution is also analyzed by changing the backorder cost from the base value to three times as much, as it was done for the sensitivity analysis of the holding cost. The results are found to be as follows:
As it can be seen from Figure 7.11, safety stock quantities and average total cost increases with increasing backorder cost and the average emission value decreases, as expected. The optimal solution is less sensitive to backorder costs compared to the holding cost values as can be seen from the Tables 7.6 and 7.7. The increase in the backorder costs results in an increase in the safety stock values at optimality, but after some point, the non-stock out probability becomes negligibly small with increased safety stocks; therefore the impact of increasing backorder cost further on safety stock values and total cost at optimality becomes less significant, which results in a decreasing slope in the safety stock and cost curves.

**Emission Cost:**
Since the optimal solution is less sensitive to the changes in the emission cost, its value is altered in a broader range (up to 50 times as much of the base case). The results are presented in Table 7.8.

<table>
<thead>
<tr>
<th>Emission Cost</th>
<th>Average Emission</th>
<th>Average Cost</th>
<th>Total Optimal Safety Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Base * 2</td>
<td>100.00%</td>
<td>100.06%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Base * 5</td>
<td>100.00%</td>
<td>100.18%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Base * 10</td>
<td>99.14%</td>
<td>100.24%</td>
<td>100.07%</td>
</tr>
<tr>
<td>Base * 25</td>
<td>89.60%</td>
<td>101.00%</td>
<td>101.87%</td>
</tr>
<tr>
<td>Base * 50</td>
<td>85.24%</td>
<td>101.48%</td>
<td>103.99%</td>
</tr>
</tbody>
</table>

As can be seen from Table 7.8, significant impacts of emission costs on the optimal solution cannot be observed until it is increased to at least 10 times of the base value. Until that point, the only effect of the increased emission cost is on the average cost, which increases slightly. Even at that value (Base*10), the effect of the change on the optimal safety stock, and therefore the average cost and the average emission is still very low. For the larger values, it can be seen from Table 7.8 the emissions drop significantly because of decreased emergency shipments, however the cost gained by the less number of emergency shipments are counteracted by the increased emission cost; therefore the average cost values stay at similar levels.

**7.7. Possible Extensions**
The simulation models take into account only the transportation as the replenishment lead time, for both regular and emergency shipments. However, although small, production process also has a variation which makes the production lead time to produce the required quantity not constant. Thus, including the production process and its lead time into the calculations would result in more accurate results. However in this case, production order and shipment order decisions should be considered separately, which will be dependent on each other. Also, forecast updates between the production’s start and its end should also be incorporated to aid shipment decisions. Therefore this extension would make the model more realistic but much more complex to build.

Table 7.7: Percentage changes compared to base case

<table>
<thead>
<tr>
<th>Backorder Cost</th>
<th>Average Emission</th>
<th>Average Cost</th>
<th>Total Optimal Safety Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Base * 2</td>
<td>98.4%</td>
<td>101%</td>
<td>102%</td>
</tr>
<tr>
<td>Base * 5</td>
<td>90.2%</td>
<td>102%</td>
<td>104%</td>
</tr>
<tr>
<td>Base * 10</td>
<td>90%</td>
<td>103%</td>
<td>105%</td>
</tr>
<tr>
<td>Base * 25</td>
<td>89.6%</td>
<td>101%</td>
<td>101.87%</td>
</tr>
<tr>
<td>Base * 50</td>
<td>85.24%</td>
<td>101.48%</td>
<td>103.99%</td>
</tr>
</tbody>
</table>
Forecasts are updated weekly, but the simulation model generates only one forecast. Since very limited information was available, it was not possible to discover any statistical consistency or a pattern in forecast updates. However, if extreme changes are anticipated in the demand, preventive actions can be done to prevent stock outs. Thus an extension in the simulation model can be possible by incorporating the weekly forecast updates.

In addition the impact of pallet size on replenishment decisions is simply ignored in the model since it is known that less than pallet size deliveries are also possible in some cases. However, the historical data shows that majority of the shipments are full pallet shipments; therefore including the impact of pallet size in calculations might increase the accuracy of the results.

Base model gives the emergency shipment decisions proactively, and it was compared with a reactive setting as a scenario analysis. However in real life, there is no pure policy in Philips about emergency shipment decisions. The planners might give emergency shipment order either proactively or reactively, depending on the situation. This decision depends on a number of factors such as the degree of urgency, the product type and its market conditions, the customer and the contractual penalties defined inside the contracts with the customer. Although it would be very difficult to model it assuming a decision rule; still, considering emergency shipments as a combination of proactive and reactive decisions would make the model more close to the current application.

As an assumption, emergency shipments are considered to be received in exactly 5 days; despite this process is also stochastic. Besides the fact that the data set available for emergency shipments was too small to fit a distribution, a lead time over one week would add complexity to the calculations in terms of goods-in-transit quantity and the determination of the that week’s arriving goods when giving proactive emergency shipment decisions.

This chapter investigated the effect of inventory management on emissions. A simulation model was introduced which represented the current system in Philips, optimal safety stock levels were derived and scenario and sensitivity analyses were conducted. It can be concluded from the whole analysis that generally, inventory has a significant impact on managing emissions, through safety stocks which influence the frequency of emergency shipments. The findings will be discussed in detail in Chapter 8.
CHAPTER 8: CONCLUSION

This chapter summarizes the findings of this thesis study, and presents recommendations for implementation and future research directions.

8.1. Summary of the Insights and Recommendations on Implementation

Sustainability is deemed to be an integral part of the company philosophy in Royal Philips Electronics. Therefore several companywide programs are running which try to improve sustainability performance of the company. EcoVision 4 is one of them and with this program Philips has a commitment to cut down its total operational carbon footprint by 25 percent by 2012, compared to base year 2007. Since 33 percent of the emissions are originating from their transport operations, transport emissions need to be reduced significantly in order to reach above mentioned targets.

This project is held in cooperation with Philips Corporate Sustainability Office and aimed to point out improvement potentials in measurement and reduction of logistical carbon dioxide emissions. The research questions and the main findings related with each research dimension are summarized below.

- "How to provide more transparency to the carbon footprint of the logistical processes of Philips?"

As a first step, the transparency of the carbon footprint of the company was assessed considering the current data availability and accuracy of the estimations. The methodology utilized in Philips for emission calculation process is very limited and allows the company to observe only a few reduction alternatives on final results (Table 3.3). Therefore, application of NTM methodology to Philips’s data would be a solution to provide more visibility to the carbon footprint; hence it could give the opportunity to decrease emissions with improvements made on several dimensions. However, considering the decentralized supply chain structure of the company and the inexistence of a companywide logistical database, it is very difficult to collect and process detailed logistical data in order to come up with transparent emission calculations. In addition, most of the data that are necessary for detailed calculations are not present in the databases, e.g. per shipment and load factor data. It is argued throughout Chapter 3 that the performances of NTM methodology and GHGP are similar at the most aggregate level in terms of transparency in settings where no detailed data is available, but NTM becomes superior when additional data becomes available. Since the availability of data in the company is very limited centrally and an IT-based database or software which can cumulate and process all data from different sectors is not existent, the calculations made using NTM methodology will not even be transparent in this setting. Thus, if the company does not make additional investments, or sign specific agreements with LSPs or carry out projects to increase the transparency in transport activities, it is not possible for them to benefit from the opportunities provided by more transparent calculation procedures.

Additionally, several suggestions were presented (Section 3.4) in order to increase the accuracy of their estimates and incorporate more variables into calculations such as load factor as a part of chargeable weight, routing for road etc. Besides, collaboration with LSPs plays an important role, because a notable amount of data which Philips does not hold is available at LSPs. Fortunately, LSPs
are willing to collaborate in terms of data sharing and offering intermodal transportation, for the sake of environmental issues.

“How can CO₂ from goods transport be decreased?”

As a second step in the research, to find answers to the second research question, a benchmark study and a literature review were conducted and several interviews were held. As a result of these studies, general reduction options were identified and then assessed in terms of their feasibilities, costs and estimated impacts on emissions. Most promising options in this analysis were chosen to be: modal shifts/intermodal transportation, inventory management, increasing forecasting accuracy and increasing load factor; and then these options were investigated with more detail on the selected deep-dive scope. The results of the analysis are summarized in Table 8.1.

Table 8.1: Summary of the findings

<table>
<thead>
<tr>
<th>Abatement Option</th>
<th>Estimated Impact</th>
<th>Studied Transport Lane</th>
<th>Possible Transport Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal shift/Intermodal Transportation</td>
<td>8%</td>
<td>Intermodal Air</td>
<td>Air/Road/Sea</td>
</tr>
<tr>
<td>Increasing Load Factor</td>
<td>3-4%</td>
<td>Road</td>
<td>Air/Road/Sea</td>
</tr>
<tr>
<td>Inventory Management</td>
<td>37%</td>
<td>Mainly Air/Sea intermodal</td>
<td>Air/Road/Sea</td>
</tr>
<tr>
<td>Forecasting</td>
<td>10%</td>
<td>Mainly Air/Sea intermodal</td>
<td>Air/Road/Sea</td>
</tr>
</tbody>
</table>

As can be seen from Table 8.1, the most promising option is found to be inventory management. In addition, the majority of the emissions were found to be originating from a small number of lanes (Section 4.1). Thus, any adjustments done over these lanes in terms of mode change and intermodal transportation or any kind of control over LSPs, might lead to notable changes in global emission results. Therefore special attention should be paid to those lanes.

“What is the relationship between inventory & transportation decisions and emissions?”

For finding an answer to this question, a Markovian and a simulation model were constructed in order to gain more insights on the relationship between inventory replenishment decisions, forecasting accuracy and carbon emissions. The studied system is a forecast-driven supply chain because of the global dispersion of the supply chain operations. Economical reasons entail such dispersions; however this creates a number of operational difficulties. During the analysis, forecast errors were found to have a notable impact on the emissions, because higher forecast error variability triggers emergency shipments. It was found beneficial for the company to keep the COV values of the forecasting errors lower than 0.5 so as to avoid steep increases in emissions.

In addition, the impact of inventory replenishment decisions on carbon emissions was found to be considerably high and mostly the emission savings go hand in hand with the cost savings. Looking at the overall inventory strategies of Philips, it can be said that special attention has been paid to decrease the inventory levels aiming to decrease inventory costs and working capital. However this policy increases emergency shipments considerably, which in turn results in a high logistical carbon footprint. Therefore, for products groups whose holding cost value is extremely small compared to emergency shipment prices, alternative inventory strategies might be better which try to keep as much inventory as possible in order to eliminate emergency shipments. In addition, for the studied system, it was found that if the emergency orders were given in a reactive manner at the end of the week, the impact of forecast errors would be eliminated and the emissions can decrease up to 20 percent for the current safety stock policy, with negligible differences in service levels (less than 0,5 percent).
“How to implement possible CO₂ reduction options?”

The final research question aims at shedding light on to the implementation of the discussed issues. Even though implementation considerations were discussed throughout the thesis, main points can be summarized as follows:

- In order to increase transparency, increasing the accuracy of the estimates and taking into account additional variables are necessary. Using NTM will provide the company with a more transparent carbon footprint. Therefore, more variables such as vehicle type information, load factor etc. should be considered in the estimations. This can only be made possible by an IT based infrastructure which can handle the storage and processing of notable amounts of data.

- Emissions could be reduced by focusing on a small number of lanes and by collaborating with LSPs to improve emissions in those lanes. In addition, new KPIs could be defined which can be used as additional criteria in LSP selection procedure.

- To increase forecasting accuracy, weekly distribution of sales could be analyzed and weekly forecasts could be generated instead of generating monthly forecasts and simply dividing them to four for weekly operations planning.

- In order to increase load factors, this statistic can also be defined as a KPI which is already planned to be done in the Lighting sector. In addition, alterations made on shipment frequencies might result significant increases on load factor.

- Safety stocks at the RDCs can be increased to feasible and reasonable levels to decrease the probability of requiring emergency shipments. This will result in substantial savings besides a notable decrease in emissions that result from express air shipments.

8.2. Directions for follow-up work

Behind the abovementioned insights, many assumptions and simplifications are hidden which create several future research directions. For instance, the model can be extended to include pallet sizes for the shipments. Despite the increase in the complexity of the model with such an extension, more realistic shipment decisions would be obtained. In addition, the assumption of suppliers having infinite capacity for regular and emergency shipments can be relaxed. This way, the impact of supplier’s capacity on emissions would be observed. Other than these, downstream shipments can also be included in the models. The contribution of the road shipments from LDCs to customers to total emission of the system would then be visible. Furthermore, modeling the current system with more than two warehouses and analyzing the impact of this on the total emissions might also generate useful insights since many products are stored in more than two warehouses.
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BU</td>
<td>Business Unit</td>
</tr>
<tr>
<td>Carbon</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COV</td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>CL</td>
<td>Consumer Lifestyle</td>
</tr>
<tr>
<td>DC</td>
<td>Distribution Center</td>
</tr>
<tr>
<td>GHGP</td>
<td>Greenhouse Gas Protocol</td>
</tr>
<tr>
<td>HC</td>
<td>Healthcare</td>
</tr>
<tr>
<td>LDC</td>
<td>Local Distribution Center</td>
</tr>
<tr>
<td>LG</td>
<td>Lighting</td>
</tr>
<tr>
<td>LSP</td>
<td>Logistics Service Provider</td>
</tr>
<tr>
<td>NTM</td>
<td>Network for Transport and Environment</td>
</tr>
<tr>
<td>RDC</td>
<td>Regional Distribution Center</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty-foot equivalent unit</td>
</tr>
</tbody>
</table>
REFERENCES


26) NTM Road, Environmental data for international cargo transport – road transport, NTM: 2008.


APPENDIX I: EMBEDDED GOVERNANCE STRUCTURE

Sustainability management at product divisions, businesses and regions receives input from:

- The Board of Management and Group Management Committee who are responsible for the strategic sustainability decisions.
- The Sustainability Board, which is chaired by a member of the Board of Management and includes a management team member from each of the product divisions, the CEO of Philips Research and the heads of Corporate Strategy, Human Resources, Legal, IT, Supply Management, Communications and Sustainability.
- The Sustainability Network that includes corporate staff members, regional and divisional sustainability managers, the CSO, as well as employees in nearly all functional areas. Sustainability Directors at the product divisions report hierarchically to management level in their product division, and functionally to the head of the CSO (Henk de Bruin), a Senior Vice President who is the secretary of the Sustainability Board (Didden, 2007).
Operational carbon footprint consists of four main components which are emissions from industrial sites, non-industrial sites, business travel and logistics. Currently logistics accounts for the 33% of the total operational emissions. Under logistics emissions from road freight, sea freight and air/express is reported. Since the contribution of rail freight is negligibly small compared to other modes of transport, it is reported under road emissions.
APPENDIX III: INPUT REQUEST TEMPLATE

Philips Information request related to CO₂ reduction Program

Dear Sir/Madam,

As a part of the project to identify the CO₂ abatement levers, we kindly ask you to provide the requested information about your shipment processes. Your input is crucial in increasing the accuracy of our CO₂ emission data and subsequent identification of reduction options. You will find attached an excel sheet listing all intermodal transport lanes that you are operating in 2009. Could you please specify on an individual lane basis the following information:

- The modality of the non-air legs together with the load factor data if available
- The type of aircrafts used in air leg together with load factor data if available

The information about your transport routes will be used internally; we will not share them with any third parties.

Information about the Excel File

In the first sheet of the attached excel file, namely “Air Transport”, all transport lanes will be listed which have been assigned to your company. The lane details include information about Origin Country, Origin Airport, Destination Country and Destination Airport.

Under title of “Air leg”, you are asked to specify the type of aircraft that was used. For aircraft types please see the Appendix. If you are not using a single dedicated aircraft type for the given lanes, it will be sufficient to list the types that are used most frequently.

Under titles of “Non-air leg I” and “Non-air leg II” (see schematic above), you are asked to specify the transport mode (rail/road/sea), distance (km) and the vehicle type you are using for the given lanes. For vehicle types please see the Appendix. If you are not using a single dedicated vehicle type for the given lanes, it will be sufficient to list the types that are used most frequently. If you only perform airport-to-airport deliveries, please leave the information requested under columns of “Non-air leg I” and “Non-air leg II” empty. In case of any other Non-air legs please add this information to the “Additional Non-air Legs” column.
**APPENDIX IV: TRANSPORT FLOW TYPES IN PHILIPS**

**Goods flows definition**

<table>
<thead>
<tr>
<th>Flow</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>• Component flows from 3rd suppliers to Philips entities</td>
</tr>
<tr>
<td></td>
<td>• Intra-Philips component flows</td>
</tr>
<tr>
<td>Mainstream</td>
<td>• Finished goods flows from 3rd suppliers (OEM) to Philips entities</td>
</tr>
<tr>
<td></td>
<td>• Intra-Philips Finished goods flows</td>
</tr>
<tr>
<td>Downstream</td>
<td>• Finished goods flows from any source to Philips’ customers</td>
</tr>
</tbody>
</table>

**Upstream**

- 3rd Supplier
- Component Factory
- OEM Supplier

**Mainstream**

- Finished Product Factory
- RDC
- LDC
- Example:
  - Greece
  - Iberia
  - India
  - China

**Downstream**

- Customer
- Consumer

**Downstream flows variants**

**Direct Shipment**: Door-to-Door delivery from OEM supplier / Philips factory to customer (typical large size shipment)

**Direct Delivery**: Door-to-Door delivery from RDC/LDC to customer

**Cross-Dock Shipments**: Shipments from factory/RDC to customers that are combined in a RDC/LDC with other shipments for the same customer into direct or network deliveries

**Network Deliveries**: Shipments to customers going through a transport network (parcel network; LTL network)
APPENDIX V: PHILIPS’ GHG BASED EMISSION CALCULATION METHOD

Calculation procedure comprises three steps:

1) Distance travelled data (km) is multiplied by the weight to find out the ton-kilometers.

\[ \text{TonKm} = \text{Km} \times \text{kg} \div 1000 \]

2) Multiply TonKm with the emission factor and divide it to 1000 in order to attain Ton CO\(_2\) emitted.

\[ \text{TonKm} \times \text{Emission} \div 1000 = \text{Ton CO}_2 \]

3) Extrapolation based on weights for the lanes for which distance information is not available.

List of emission factors used in the calculations can be seen below:

**Table V.1: List of Emission factors used by Philips**
APPENDIX VI: AGGREGATE LEVEL COMPARISON OF NTM AND GHG

Figure VI.1: Comparison between NTM methodology and GHGP at the highest aggregate level

In Figure VI.1, the calculation methodology of NTM and GHGP (Philips) at the most aggregate level is visualized. It can be claimed that, at this level, analysis made with NTM methodology is equivalent to the analysis made with GHGP since both of methods utilize constant emission factors per weight or per associated unit. However, one should also take into account the differences in emission factors. But it is beyond the scope of this project to judge which emission coefficient is more reliable.
APPENDIX VII: AGGREGATION BIAS EXAMPLE

Aggregation of cumulative weights and using average distance values for the calculations results in reporting errors. Examples of over reporting and under reporting errors are given below:

Table VII.1: Example of Over Reporting (McKenzie, 2010)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Weight</th>
<th>Emission Factor</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment 1</td>
<td>10 km</td>
<td>4500 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Shipment 2</td>
<td>40 km</td>
<td>500 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Aggregation</td>
<td>25 km</td>
<td>5000 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Difference:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table VII.2: Example of Under Reporting (McKenzie, 2010)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Weight</th>
<th>Emission Factor</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment 1</td>
<td>10 km</td>
<td>500 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Shipment 2</td>
<td>40 km</td>
<td>4500 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Aggregation</td>
<td>25 km</td>
<td>5000 kg</td>
<td>72 kg CO2/kgkm</td>
</tr>
<tr>
<td>Difference:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX VIII: SUGGESTIONS TO INCREASE ACCURACY IN EMMISSION ESTIMATIONS

❖ Rail emissions can be distinguished from road emissions which might in turn increase accuracy and help the company to show the impact of a possible transport mode shift on emissions.
❖ Transport mode of express shipments can be requested from the providers together with the performance data used in the KPI reports. If providers are not willing to share such data, estimates on road/air ratio can be created and used in the calculations for approximation.
❖ Information about container types and loading degrees can be taken into account while calculating the weights of the sea freight containers. Weight estimates of several container types are available in documents posted by NTM and can be used for the data points where container type data is available. In addition inclusion of loading degree in weight estimations may provide the company to observe the impact of several packaging initiatives on yearly figures.
❖ Instead of using weight in the road emission estimations, chargeable weight might be used in order to ensure consistency in the calculations.
❖ In real life, routing is fixed for several lanes of road transport and to some extent this information is available in the company. A research can be made, which uses a similar approach such as the previously mentioned studies for determination of non-road legs of sea and air, in order to determine an estimate of positioning distance and routing on the distance travelled via road. If such an estimate is updated yearly; this may result in an increased accuracy in estimations and makes the impact of changes in the supply chain structures visible on results.
❖ In order to eliminate the aggregation bias, more detailed information on origin and destination points of the shipments should be made available. In addition to aggregation bias, there can be deviations because of the extrapolations made. Instead of extrapolations county to country distances can be used to come up with better estimates.
APPENDIX IX: BENCHMARK WITH PEER GROUP AND COMPETITORS

Reduction options listed in the sustainability reports:

**Toshiba**
- Modal shift: Rail transport operations in Japan
- Optimal modes of transport
- Rating the load factor of trucks
- Improvements in load and delivery route efficiencies
- Consolidating DCs

**Hitachi**
- Reduce weight and size of products
- Reduce packaging
- Modal shift to rail and sea
- Increase truck loads by sharing joints with other companies

**General Electric**
- Ship optimiser for trains: System automatically controls a locomotive’s throttle while minimising the use of Light Management Systems Optimised Decent

**Electrolux**
- Responsible sourcing program
- Restructuring shifting location of production
- Environmentally sustainable design
- Rail transport in transport: 7000 rail transports in Europe for household appliances accounted for 4.5% of all transport from factories to regional DCs

**Panasonic**
- Promotion of environmentally conscious transport: shift to rail transportation in Japan
- Improvements in lead factors: reduction of packaging, joint transportations
- Introduction of eco-trucks: hybrid trucks and eco-drive
- Introduction of bio-diesel: canister, collection & refining, use as fuel
- Strengthening alliances with other Green logistics companies: Green Partnership
- Working at home: roughly 5000 Panasonic employees are working from home
- Less travel policy

**Bosch**
- Optimizing the interlinking of road, rail and sea transport routes: block rail transport from Poland to Haarlem
- Freight space optimisation: reducing the number of transshipments required
- Transport packaging: reducing the average weight of transport packaging from 2.65 kg to 2.23 kg

**Canon**
- Modal shifts: usage of ships and railroads in Japan: first company that acquires Eco-Fall Mark from Japan’s Ministry of Land, Infrastructure and Transport
- Reduce mode transport distances: loading methods and distribution processes
- Simplify packaging through innovations of technologies and product structuring
- Increase packaging efficiency through the use of returnable packaging
- Optimize localised listing

**Sony**
- Collaboration with logistic providers to reduce the impact of transport via its overall carbon footprint
- The efficient and optimized means of transport

Phils position compared to others:

**Reported in the Sustainability Report:**
- Modal shift from air to sea
- Sustainable supplier selection
- Improved lead factors
  - Improved container utilization
  - Improved truck utilization
- Less travel policy by promoting video conferencing

**Done but not Reported:**
- Reduce packaging
- Reusable packaging
- Supply Chain Restructuring
- Alliances with Green logistic companies
- Improve delivery route
- Optimized means of transport

**Future plans:**
- Sustainable design
- Increase loading degrees in Lighting

**Not being done:**
- Modal shift to rail
- Eco-trucks
- Bio-diesel
- Work at home
- Modal shift from road to inland sea
APPENDIX X: FACTORS THAT INFLUENCE LOGISTICAL CARBON EMISSIONS

Figure X.1: Factors that Influence logistical carbon footprint
APPENDIX XI: SUPPLY NETWORK OF MHN-TD IN EUROPE

Figure XI.1: Supply Network of MHN-TD in Europe

*For the distribution center in Pila, PL the sales regions are:*
Lighting Belgium, Lighting Czech Republic, Lighting Denmark, Lighting Finland, Lighting Germany, Lighting Hungary, Lighting Netherlands, Lighting Norway, Lighting Poland, Lighting Romania, Lighting Russia, Lighting Slovakia, Lighting Sweden, Lighting Switzerland, Lighting Turkey, Lighting UK

*For the distribution center in VSG, France the sales regions are:*
Lighting France, Lighting Greece, Lighting Italy, Lighting Portugal, Lighting Spain
## APPENDIX XII: DETAILS ON GOODS FLOW

### Air Transport

#### Production Country
<table>
<thead>
<tr>
<th>Country</th>
<th>Distance to airport (km)</th>
<th>Most frequently used vehicle type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHINA</td>
<td>83</td>
<td>Light truck (3.7 - 7 mT)</td>
</tr>
<tr>
<td>CHINA</td>
<td>83</td>
<td>Light truck (3.7 - 7 mT)</td>
</tr>
</tbody>
</table>

#### Origin Airport
<table>
<thead>
<tr>
<th>Origin Airport</th>
<th>Dest. Airport</th>
<th>Distance in air (km)</th>
<th>Most frequently used airplane type</th>
<th>Distance to DC (km)</th>
<th>Most frequently used vehicle type</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVG</td>
<td>CDG</td>
<td>8888</td>
<td>767-300</td>
<td>40.7</td>
<td>Heavy truck (16 - 26 mT)</td>
</tr>
<tr>
<td>PVG</td>
<td>WARSAW</td>
<td>8007</td>
<td>747-400 Freighter</td>
<td>369</td>
<td>Medium truck (7 - 18 mT)</td>
</tr>
</tbody>
</table>

### Sea Transport

#### Distance to Origin Port
<table>
<thead>
<tr>
<th>Distance to Origin Port</th>
<th>Origin Port</th>
<th>Distance in Sea</th>
<th>Dest. Port</th>
<th>Vessel Type</th>
<th>Container Types</th>
<th>Distance to DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>SHANGHAI</td>
<td>20796</td>
<td>SZCZECIN</td>
<td>Containership (Post Panamax)</td>
<td>20', 40', 40' HC</td>
<td>173</td>
</tr>
<tr>
<td>37</td>
<td>SHANGHAI</td>
<td>19102</td>
<td>LE HARVE</td>
<td>Containership (Post Panamax)</td>
<td>20', 40', 40' HC</td>
<td>221</td>
</tr>
</tbody>
</table>
APPENDIX XIII: DETAILS OF THE EMISSION CALCULATIONS MADE IN CHAPTER 5

Calculations made in Section 5.1.3:

The calculations were done based on NTM methodology (NTM Air, 2008; NTM Road, 2008; NTM Sea, 2008). Very detailed information was available for road transport for mainstream lanes, such as the vehicle type data and load factor of each shipment. Therefore original parameters are used in the calculations where detailed data available. For the lanes where details can not be found, the vehicle type is assumed to be Tractor + semi-trailer (< 40 mT) which is found to be the most frequently used vehicle for both mainstream and downstream flows and the load factor is taken as 48.09% which is the average loading degree that is calculated using an extensive data set obtained from a project on increasing loading degrees of Lighting sector (Source: Marcin Pajak, Philips). Since no information is available on positioning, a positioning distance of 20% is assumed. Since all the calculations are made by using TERRA tool, terrain information is also taken into account in the calculations.

For air and sea calculations, most frequently used vehicle types are learned from the LSPs during the interviews. Details on this can be seen from Appendix XI. In the study of Van den Akker (2009), NTM methodology was applied and the average load factors for dedicated cargo aircrafts was found as 80%. Since the most frequently used aircraft types are in the group of dedicated cargo aircrafts in this case, an average load factor of 80% is assumed in the calculations for air transport. For sea transport, the average load factor value defined by NTM (NTM Sea, 2008) is used. Actual data was available for the road legs of sea and air shipments and used in the calculations. For other variables included in the TERRA tool, the defaults values are used.

Calculations made in Section 5.2:

For the intermodal options, the vehicle type for road is assumed to be Tractor + semi-trailer (< 40 mT) with an average load factor of 48.09% since it is the most frequently used vehicle within the firm. The fuel consumption is then calculated as:

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Highway</th>
<th>Rural</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Consumption</td>
<td>0.290441</td>
<td>0.309829</td>
<td>0.3918744</td>
</tr>
</tbody>
</table>

Hoen et al. (2010) calculated the average distance travelled on urban roads as 8.9km (in total 17.8 km for a route). The same approach in that paper as adopted. Then the function of the fuel consumption becomes:

\[ FC = 1.8055 + 0.29044D \]

And the associated emissions per shipment can be calculated as:

\[ EM = 4968.8858 + 799.3070D \]

Therefore unit emissions per kg shipped is found by dividing total emissions to 19236 which is the total capacity of the vehicle assuming a 48.09 percent load factor.
APPENDIX XIV: STATISTICAL ANALYSIS OF LOAD FACTORS

Figure XIV.1: Load factor values in different quarters

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F-Ratio</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>0.119938</td>
<td>3</td>
<td>0.0399795</td>
<td>2.44</td>
<td>0.0629</td>
</tr>
<tr>
<td>Within groups</td>
<td>42.9935</td>
<td>2620</td>
<td>0.0164097</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (Corr.)</td>
<td>43.1134</td>
<td>2623</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 2.43633, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is greater than or equal to 0.05, there is not a statistically significant difference between the means of the 4 variables at the 95.0% confidence level.

Figure XIV.2: Load factor values of different lanes

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F-Ratio</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>4.40445</td>
<td>5</td>
<td>0.880889</td>
<td>59.27</td>
<td>0.0000</td>
</tr>
<tr>
<td>Within groups</td>
<td>38.9413</td>
<td>2620</td>
<td>0.0148631</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (Corr.)</td>
<td>43.3458</td>
<td>2625</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ANOVA table decomposes the variance of the data into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 59.2669, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the 6 variables at the 95.0% confidence level. To determine which means are significantly different from which others, select Multiple Range Tests from the list of Tabular Options.
APPENDIX XV: ESTIMATION OF PARAMETERS FOR OPTIMIZATION MODEL

Demand:
Weekly sales data is available from year 2007. However it is not the actual amounts deducted from stocks each week but the amount of billed order quantities. Because of this peaks are observed at the end of each month and each year due to month closure and year closure as can be seen from Figure XV.1.

The peaks are handled by allocating the extra amounts at the ends of the months and years to the previous weeks, in a weighted manner. In other words, the excess demands over the month’s or the year’s average demand are calculated for the weeks facing closure, and this amount is allocated to the previous weeks depending on the weights of the demands of these weeks.

Individual Demand Distributions:
The demand data which was calculated with the procedure explained above is fitted to Gamma distribution using StatGraphics software. The results of the goodness of fit tests are presented below.

### Goodness-of-Fit Tests for Pila Demand

<table>
<thead>
<tr>
<th>Kolmogorov-Smirnov Test</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPLUS</td>
<td>0.0562534</td>
</tr>
<tr>
<td>DMINUS</td>
<td>0.0430074</td>
</tr>
<tr>
<td>DN</td>
<td>0.0562534</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.622758</td>
</tr>
</tbody>
</table>

The StatAdvisor
This pane shows the results of tests run to determine whether Pila Demand can be adequately modeled by a gamma distribution.
Since the smallest P-value amongst the tests performed is greater than or equal to 0.05, we can not reject the idea that Pila Demand comes from a gamma distribution with 95% confidence.

### Goodness-of-Fit Tests for VSG Demand

<table>
<thead>
<tr>
<th>Kolmogorov-Smirnov Test</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPLUS</td>
<td>0.0635061</td>
</tr>
<tr>
<td>DMINUS</td>
<td>0.0238165</td>
</tr>
<tr>
<td>DN</td>
<td>0.0635061</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.475149</td>
</tr>
</tbody>
</table>

The StatAdvisor
This pane shows the results of tests run to determine whether VSG Demand can be adequately modeled by a gamma distribution.
Since the smallest P-value amongst the tests performed is greater than or equal to 0.05, we can not reject the idea that VSG Demand comes from a gamma distribution with 95% confidence.

**Cumulative Demand Distribution for Markov Chain:**
In order to simplify the calculations and make the model easily solvable using MATLAB software, the total demand and inventory is assumed to be multiples of a thousand. Therefore individual demand values of the two warehouses are summed up and then divided by 1000 and the distribution of the resulting values is fitted to Gamma (shape=3.5758; scale = 4.6921) distribution using StatGraphics. The result of the goodness of fit test and the shape of the distribution is given below. Even thought the demand is continuous, values are rounded up when calculating the ending inventory levels since they need to have discrete values for the structure of the Markov chain.

**Goodness-of-Fit Tests for Total Demand per week**

<table>
<thead>
<tr>
<th>Kolmogorov-Smirnov Test</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPLUS</td>
<td>0.0699542</td>
</tr>
<tr>
<td>DMINUS</td>
<td>0.0378594</td>
</tr>
<tr>
<td>DN</td>
<td>0.0699542</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.347791</td>
</tr>
</tbody>
</table>

**Unit Emissions:**
The emissions calculated in Section 5.1.3 by TERRA tool are divided to the total number of products shipped on each lane and the average of those values are taken to assign values to unit emissions.

**Emission Cost:**
Air emissions are expected to have similar cost values with the current emissions included in EU ETS because European Commission tries to integrate aviation into the existing EU ETS as far as possible. Thus the emission price is taken as €15 per ton CO₂ emitted. Emissions from road and sea transport are also assumed to have the same price.

**Transportation Costs:**

Air Freight:

Unit air freight cost was necessary to calculate monetary values of the emergency shipments made from Asia to Europe. To calculate the air transportation cost per product up-to-date cost values are used for the actual air ports. Air freight cost comprises of several cost components which are listed in the table below:

**Table XV.1: Air freight cost components**

<table>
<thead>
<tr>
<th>Included Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight per kg</td>
</tr>
<tr>
<td>Airport terminal handling charges destination - per kg</td>
</tr>
<tr>
<td>Customs clearance destination - per shipment</td>
</tr>
<tr>
<td>Delivery to door per kg</td>
</tr>
<tr>
<td>Fuel surcharge (kg)</td>
</tr>
</tbody>
</table>
In Lighting sector, not only freight cost but also holding cost of the goods in transit is also included in the transportation cost. And the total cost is calculated using the formula below:

\[ TC = VOL \times (FR + Vdens. \times CoC \times TT) \]

where

- **TC**: total cost
- **VOL**: volume \([m^3]\)
- **FR**: freight cost \([€/m^3]\)
- **Vdens.**: cargo value density \([€/m^3]\)
- **CoC**: cost of capital \([%/day]\)
- **TT**: transit time \([days]\)

The same procedure was applied and actual costs per each shipment are calculated and by dividing the total cost to the total quantity of the products carried, a cost value for the transport of unit of product is assigned.

- **Sea Freight:**

  A historical data for the same lanes was present for the air freight and sea freight costs per kg shipped. The ratio of air cost to sea cost is taken and this coefficient is multiplied by unit air cost to assign a value to unit sea freight cost.

- **Road Freight:**

  No data was available on the selected lanes. In another up-to-date (Aug. 2010) shipment file, shipments which have approximately the same distance with the lane between RDCs are sorted and price per weight of kg shipped is averaged. The resulting value was reasonable and as expected when compared to other cost values stated above.

**Inventory Related Costs:**

Two costs are associated with inventory: holding cost and backorder cost.

- **Holding cost:**

  In order to calculate the holding cost, information is requested from the financial controllers of the warehouses and detailed information could be attained from the distribution center in Pila. The cost of storing products consists of the listed factors:

  **Table XV.2: Storage Costs**

<table>
<thead>
<tr>
<th>Included Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outward freight</td>
</tr>
<tr>
<td>Forwarding, VAS</td>
</tr>
<tr>
<td>Warehousing, Handling, Storage</td>
</tr>
</tbody>
</table>

  The monetary value of the above mentioned parameters from (Jan-Jul 2010) is divided to total number of products stored in the stock point during that period and the number of weeks and a cost value is assigned per unit product. In addition to this cost, obsolescence costs, price devaluation
costs etc., which is calculated by multiplying the value of the product with weekly cost of capital, is added to form the unit holding cost of a product one week.

- **Backorder cost:**

Backorder costs are related to direct costs such as extra administration costs, contractual penalties, interest on the profit which cannot be obtained because of the backorder, etc; and indirect costs such as loss of customer goodwill, decline in the future demand or market share (Liberopoulos et al., 2010). These tangible and intangible costs are difficult to estimate because of data unavailability and the unpredictability of the market conditions. Without loss of generality, the backorder costs were calculated using the newsvendor equation, which is:

\[
\alpha = \frac{c_u}{c_u + c_o}
\]

where \( c_u \) is the underage (backorder) cost, \( c_o \) is the overage (holding) cost and \( \alpha \) is the target service level (Silver et al., 1998). The assumed backorder cost for 95% service level becomes 19 times the inventory holding cost.

The resulting list of estimated parameters can be seen as follows:
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean period demand</td>
<td>5664,722</td>
</tr>
<tr>
<td>Std. period demand</td>
<td>2942,178</td>
</tr>
<tr>
<td>Regular shipment cost (per product)</td>
<td>0,018382</td>
</tr>
<tr>
<td>Emergency shipment cost (per product)</td>
<td>0,143927</td>
</tr>
<tr>
<td>Air distance</td>
<td>8007</td>
</tr>
<tr>
<td>Road distance to airport</td>
<td>83</td>
</tr>
<tr>
<td>Road distance from airport</td>
<td>369</td>
</tr>
<tr>
<td>Sea distance</td>
<td>20796</td>
</tr>
<tr>
<td>Road distance to seaport</td>
<td>37</td>
</tr>
<tr>
<td>Road distance from seaport</td>
<td>173</td>
</tr>
<tr>
<td>Unit emission air (per product)</td>
<td>0,343817</td>
</tr>
<tr>
<td>Unit emission sea (per product)</td>
<td>0,011362</td>
</tr>
<tr>
<td>Mean period demand</td>
<td>11113,47</td>
</tr>
<tr>
<td>Std. period demand</td>
<td>7357,278</td>
</tr>
<tr>
<td>Regular shipment cost (per product)</td>
<td>0,019099</td>
</tr>
<tr>
<td>Emergency shipment cost (per product)</td>
<td>0,149544</td>
</tr>
<tr>
<td>Air distance</td>
<td>8888</td>
</tr>
<tr>
<td>Road distance to airport</td>
<td>83</td>
</tr>
<tr>
<td>Road distance from airport</td>
<td>40,7</td>
</tr>
<tr>
<td>Sea distance</td>
<td>19102</td>
</tr>
<tr>
<td>Road distance to seaport</td>
<td>37</td>
</tr>
<tr>
<td>Road distance from seaport</td>
<td>221</td>
</tr>
<tr>
<td>Unit emission air (per product)</td>
<td>0,38683</td>
</tr>
<tr>
<td>Unit emission sea (per product)</td>
<td>0,010436</td>
</tr>
<tr>
<td>Transhipment cost</td>
<td>0,050398</td>
</tr>
<tr>
<td>Chargable weight of the product (kg)</td>
<td>0,081583</td>
</tr>
<tr>
<td>Volume of the product (CDM)</td>
<td>0,624</td>
</tr>
<tr>
<td>Weight of the product (kg)</td>
<td>0,053251</td>
</tr>
<tr>
<td>Inter RDC road distance</td>
<td>1383</td>
</tr>
<tr>
<td>Avg. loading factor for road</td>
<td>0,5163</td>
</tr>
<tr>
<td>Unit emission inter-RDC (per product)</td>
<td>0,003564</td>
</tr>
<tr>
<td>Value density</td>
<td>5608,974</td>
</tr>
<tr>
<td>Holding cost (weekly per product)</td>
<td>0,004712</td>
</tr>
<tr>
<td>Backorder cost</td>
<td>0,08951</td>
</tr>
</tbody>
</table>
APPENDIX XVI: MARKOV CHAIN MODEL ILLUSTRATION

Transition matrix calculation procedure is explained using a simplified example as given below. Upper inventory limit (U) was taken as 4, and emergency level (E) was taken as -2. Two matrices are illustrated; the first one considers both stock locations separately and takes into account the lateral transshipments between them, and the second one combines the two warehouses and neglects lateral transshipments.

**Assumption:** Normally distributed demand

**Parameter values for the first matrix:**

| E(D1)=E(D2)= | 1 |
| σ(D1)=σ(D2)= | 0.3 |
| Q= | 2 |
| E(D1+D2)= | 2 |
| σ(D1+D2)= | 0.4 |

**Transition matrix including lateral transshipments:**

<table>
<thead>
<tr>
<th></th>
<th>(2,2)</th>
<th>(2,1)</th>
<th>(2,0)</th>
<th>(1,2)</th>
<th>(1,1)</th>
<th>(1,0)</th>
<th>(0,2)</th>
<th>(0,1)</th>
<th>(0,0)</th>
<th>(0,-1)</th>
<th>(-1,0)</th>
<th>(-1,-1)</th>
<th>sum of prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2,2)</td>
<td>0.999142</td>
<td>0.000429</td>
<td>0.0000428876</td>
<td>1,840938E-07</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(2,1)</td>
<td>0.000429</td>
<td>0.499357</td>
<td>0.499784256E-07</td>
<td>0.0000029446</td>
<td>1,21423E-06</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(2,0)</td>
<td>0</td>
<td>0.499785</td>
<td>0.490578395</td>
<td>0</td>
<td>0.00021453</td>
<td>0.000209848</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(1,2)</td>
<td>0.25</td>
<td>0.249785</td>
<td>0.0000105829</td>
<td>0.24978547</td>
<td>0.24975124</td>
<td>0.0002010448</td>
<td>0.0000001053</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(1,1)</td>
<td>0</td>
<td>0</td>
<td>0.000000465531</td>
<td>0</td>
<td>0.24978547</td>
<td>0.4907898973</td>
<td>0</td>
<td>0.24975124</td>
<td>0.000214346</td>
<td>1,840938E-07</td>
<td>5.61382E-15</td>
<td>6E-15</td>
<td>6E-15</td>
</tr>
<tr>
<td>(1,0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(0,2)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(0,1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.24978547</td>
<td>0.24978547</td>
<td>0.000209848</td>
<td>0.4907898973</td>
<td>0.000214346</td>
<td>1,840938E-07</td>
<td>5.61382E-15</td>
<td>6E-15</td>
</tr>
<tr>
<td>(0,0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(-1,0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>(-1,-1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Parameter values for the second matrix:**

| E(D1+D2)= | 2 |
| σ(D1+D2)= | 0.4 |
| Q= | 2 |

**Transition matrix combining warehouses:**

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>-1</th>
<th>-2</th>
<th>sum of prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.990789</td>
<td>0.009211</td>
<td>1,21423E-06</td>
<td>7.68718E-13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.490789</td>
<td>0.0009209848</td>
<td>1,21423E-06</td>
<td>7.68718E-13</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.009211</td>
<td>0.490789</td>
<td>0.490788937</td>
<td>0.009209848</td>
<td>1,21423E-06</td>
<td>7.68718E-13</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.009211</td>
<td>0.490788937</td>
<td>0.490788937</td>
<td>0.009209848</td>
<td>1,21423E-06</td>
<td>7.68718E-13</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.009211063</td>
<td>0.490788937</td>
<td>0.490788937</td>
<td>0.009209848</td>
<td>1,21423E-06</td>
<td>7.68718E-13</td>
</tr>
<tr>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
APPENDIX XVII: SIMULATION MODEL WITH PROACTIVE EMERGENCY SHIPMENTS

The structure, variables, parameters and attributes of the simulation model are explained as follows:

**Signal-Based Structure:**
The simulation works via *Signals*, i.e. all shipment orders and demand realization are given as signals when applicable. When warehouses receive these signals, they place the orders or realize the demand according to the current variables representing the quantities. Signal-based structure of the model is advantageous for two reasons:

- For a better representation (in order not to get a spaghetti appearance)
- For a better control of the sequence of events.

**Periodic Review:**
In the beginning of each week, a periodic review starts with generating:

- A forecast for the period to which the regular order is expected to arrive,
- A forecast and the actual demand for the upcoming period,
- Regular order quantities for both Pila and VSG.

Considering the forecasted demands of the upcoming period, current inventory positions and the goods which are expected to arrive within that period, emergency shipment decisions are given via a branch. After the branch, emergency shipment signals are sent and a delay of 6.99 days is utilized in order to give lateral shipment decisions and realize the demand at the end of the week, but before the next periodic review commences. During this delay, goods are received from given emergency shipments and the regular shipments which were expected to arrive that week. After that delay, lateral transshipments are sent if necessary and finally demand is realized from the warehouses. Finally; cost, emission and performance statistics are recorded at the end of the period.

This process is depicted in the Arena screenshots of the simulation model below:

![Diagram of Elements in the Simulation Model](image)

**Figure XVII.1: Elements in the Simulation Model**
The figure above only contains the elements which are used in the simulation, and a small periodic entity flow which uses the Write block to keep record of the daily states for verification. The periodic review period flow is shown in the figure on the next page.
Figure XVII.2: Review Flow in the Simulation Model
Finally, the figure below shows the shipment processes and the demand realization for both warehouses.

Figure XVII.3: Shipments Flows of Regular and Emergency Orders, and Demand Realization in the Simulation Model
Variables and Attributes:

**ATTRIBUTES**

*QuantityEmergency*: Quantity carried by the emergency shipment

*Dem*: Demand of the expected arrival period of the regular shipment

*Quantity*: Quantity carried by the regular shipment

*Leadtime*: Generated lead time of the regular order

**VARIABLES**

*Variables related to inventory and orders*:

*PilaINVinitial*: Initial inventory of Pila in the beginning of the period

*VSGINVinitial*: Initial inventory of VSG in the beginning of the period

*PilaINV*: Inventory of Pila

*VSGINV*: Inventory of VSG

*ROQ1*: Regular order quantity of Pila per period

*ROQ2*: Regular order quantity of VSG per period

*LTQ1*: Lateral transshipment quantity from Pila to VSG per period

*LTQ2*: Lateral transshipment quantity from VSG to Pila per period

*ESQ1*: Emergency shipment quantity of Pila per period

*ESQ2*: Emergency shipment quantity of VSG per period

*DpilaNow*: Forecasted demand of the upcoming week for Pila

*DVSGNow*: Forecasted demand of the upcoming week for VSG

*SS1*: Safety Stock of Pila

*SS2*: Safety Stock of VSG

*SSem1*: Emergency stock of Pila

*SSem2*: Emergency stock of VSG

*D1*: Actual demand of Pila per period

*D2*: Actual demand of VSG per period

*Ftotal1*: Total forecasts during shipment lead time of Pila

*Ftotal2*: Total forecasts during shipment lead time of VSG

*GIT1*: Total goods in transit on the way to Pila

*GIT2*: Total goods in transit on the way to VSG

*DPila*: Forecasted demand for the regular shipment’s expected arrival period for Pila

*DVSG*: Forecasted demand for the regular shipment’s expected arrival period for VSG

*BO1*: Backorder of Pila per period

*BO2*: Backorder of VSG per period

*GA2P*: Goods arriving to Pila within the upcoming week

*GA2V*: Goods arriving to VSG within the upcoming week

*FerrorDev1*: Standard deviation of forecast error of Pila

*FerrorDev2*: Standard deviation of forecast error of VSG

*FEpila*: Generated forecast error of Pila per period

*FEVSG*: Generated forecast error of Pila per period

**Costs**

*Cr1*: Cost of regular shipment to Pila per unit
$Cr_2$: Cost of regular shipment to VSG per unit
$Ce_1$: Cost of emergency shipment to Pila per unit
$Ce_2$: Cost of emergency shipment to VSG per unit
$C_{em}$: Emission cost per unit emission
$C_l$: Cost of lateral transshipment between Pila and VSG per unit
$hold$: Inventory holding cost per unit
$Pen_a$: Backorder penalty cost per unit
$PC$: Cost of the period
$TC$: Total cost

**Emissions:**
$UER_1$: Unit emission of regular shipments to Pila
$UER_2$: Unit emission of regular shipments to VSG
$UEE_1$: Unit emission of emergency shipments to Pila
$UEE_2$: Unit emission of emergency shipments to VSG
$UET$: Unit emission for lateral transshipments
$EMP$: Emission per period
$EMT$: Total emission

**Statistical Purpose Variables:**
$TII_1$: Sum of the initial inventory of Pila
$TII_2$: Sum of the initial inventory of VSG
$TGA_1$: Sum of the goods arrived to Pila
$TGA_2$: Sum of the goods arrived to VSG
$TBO_1$: Total amount of backorders of Pila
$TBO_2$: Total amount of backorders of VSG
$TD_1$: Total demand of Pila
$TD_2$: Total demand of VSG
$TROQ_1$: Total regular orders placed by Pila
$TROQ_2$: Total regular orders placed by VSG
$TESQ_1$: Total emergency orders placed by Pila
$TESQ_2$: Total emergency orders placed by VSG
$TEI_1$: Sum of the ending inventory of Pila
$TEI_2$: Sum of the ending inventory of VSG
$TLTQ_1$: Total lateral shipments from Pila to VSG
$TLTQ_2$: Total lateral shipments from VSG to Pila
$TGIT_1$: Total goods in transit of Pila
$TGIT_2$: Total goods in transit of VSG
APPENDIX XVIII: ADDITIONAL PARAMETER ESTIMATIONS FOR SIMULATION

Parameters which are introduced for the simulation model are listed as follows:

Lead time Distributions:
Lead times of regular sea shipments were obtained from 2009 shipments file, and the data are fitted to normal distribution for both Pila and VSG. The distributions are found to be Normal with a mean of 54.32 and a standard deviation of 15.38 and Normal with a mean of 40.18 and a standard deviation of 9.96 for Pila and VSG consecutively.

Goodness-of-Fit Tests for VSG Sea LT

<table>
<thead>
<tr>
<th>Kolmogorov-Smirnov Test</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPLUS</td>
<td>0.134178</td>
</tr>
<tr>
<td>DMINUS</td>
<td>0.114669</td>
</tr>
<tr>
<td>DN</td>
<td>0.134178</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.214662</td>
</tr>
</tbody>
</table>

The StatAdvisor
This pane shows the results of tests run to determine whether VSG Sea LT can be adequately modeled by a normal distribution.

Since the smallest P-value amongst the tests performed is greater than or equal to 0.05, we can not reject the idea that VSG Sea LT comes from a normal distribution with 95% confidence.

Forecast Error Distributions:
Only limited number of forecast data was available (5 monthly forecasts in total), thus it was not possible to obtain the forecast error distributions from the actual data. To prevent negative demand values, forecast errors were assumed to follow a truncated normal distribution. Interviews revealed that the forecast errors are not highly variable (Coefficient of Variation over 0.6), but also not very stable (Coefficient of Variation under 0.3). Making an educated guess, the coefficients of variation for the forecast errors were assumed to be 0.45 for both Pila and VSG. Although they are assumed not to be representative, COV of the forecast errors of the available monthly data was 0.44, which is very close to the assumed value.

Safety Stocks:
Estimation of the safety stock values is complex when both demand and lead time are stochastic. Silver et al. (1998) suggests an approach for the calculation of combined standard deviation of demand and lead time and thus the safety stock, when both of them are normally distributed. However, in our case, demand fits gamma distribution, and in that situation Silver et al. (1998) suggests using the spreadsheet approach developed by Tyworth et al. (1996). This approach is stated as follows:

- Find a lead time-demand distribution for each possible lead time value, and calculate the probabilities.
- Find the Expected Shortage per Review Cycle for each newly defined distribution.
- Obtain the weighted averages of the ESPRC values using the probabilities.
- Use the weighted average to find an optimal reorder point.
- Subtract the expected demand during expected lead time from the reorder value to find the required safety stock.
ESPRC formulas provided by Silver et al. were employed and for 90% fill rate, the safety stock values were found as 9951 for Pila and 21068 for VSG. These safety stock values also approximately correspond to the previously mentioned 14-day expected demand policy of Philips. Resulting values of these parameters are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Lead Time Distribution</th>
<th>Forecast Error Distribution</th>
<th>Safety Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pila</td>
<td>Normal (54.32;15.38)</td>
<td>Truncated Normal (0;2549)</td>
<td>9551</td>
</tr>
<tr>
<td>VSG</td>
<td>Normal (40.18;9.96)</td>
<td>Truncated Normal (0;5001)</td>
<td>21068</td>
</tr>
</tbody>
</table>
APPENDIX XIX: VERIFICATION OF THE SIMULATION MODEL

Following figure is the output of TRACE command in the Run Controller of Arena. Starting from time 700 and ending at 707, it covers a single review period.

And the figure below shows the state and decision variables which correspond to above given output.

It can be seen that the regular order quantities are given as they should be, and the decisions regarding emergency shipments and lateral transshipments are given correctly.
### APPENDIX XX: ARENA SIMULATION OUTPUT

**ARENA Simulation Results**

**Project:** Emission Simulation

**Analyst:** Hande Koc

**Run execution date:** 8/14/2010

**Model revision date:** 8/14/2010

**Replication ended at time:** 182.0 Days

**Base Time units:** Days

#### DISCRETE-CHANGE VARIABLES

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Average</th>
<th>Half Width</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Final Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Inv Pila</td>
<td>469.11</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>1122.8</td>
<td>1122.8</td>
</tr>
<tr>
<td>Total Lateral Pila</td>
<td>934.36</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>4988.2</td>
<td>4988.2</td>
</tr>
<tr>
<td>Total Lateral VSG</td>
<td>284.76</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>1233.7</td>
<td>1233.7</td>
</tr>
<tr>
<td>Total Regular Orders Pila</td>
<td>73195.</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>1.408E+05</td>
<td>1.408E+05</td>
</tr>
<tr>
<td>Total Regular Orders VSG</td>
<td>1.28E+05</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>2.01E+05</td>
<td>2.61E+05</td>
</tr>
<tr>
<td>Average Inv VSG</td>
<td>924.87</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>2051.0</td>
<td>2051.0</td>
</tr>
<tr>
<td>Average Total Cost</td>
<td>25.48E-3</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>52.0E-3</td>
<td>52.0E-3</td>
</tr>
<tr>
<td>VSG Ending Inventory</td>
<td>1734.6</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>4999.4</td>
<td>17701.1</td>
</tr>
<tr>
<td>Pila Ending Inventory</td>
<td>9831.1</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>27403.0</td>
<td>15473.1</td>
</tr>
<tr>
<td>SL VSG</td>
<td>.99916</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>1.0000</td>
<td>.99773</td>
</tr>
<tr>
<td>Average Total Emission</td>
<td>14.60E-3</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>29.2E-3</td>
<td>29.2E-3</td>
</tr>
<tr>
<td>SL Pila</td>
<td>6820.0</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>13559.1</td>
<td>13559.1</td>
</tr>
<tr>
<td>Total Emergency Pila</td>
<td>850.85</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>3944.1</td>
<td>3944.1</td>
</tr>
<tr>
<td>Total Emergency VSG</td>
<td>3445.0</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>4898.1</td>
<td>4898.1</td>
</tr>
<tr>
<td>Total Goods Arrived to Pila</td>
<td>1.358E+05</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>2.657E+05</td>
<td>2.657E+05</td>
</tr>
<tr>
<td>Backorder Pila</td>
<td>.00000</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>.00000</td>
<td>.00000</td>
</tr>
<tr>
<td>Backorder VSG</td>
<td>187.27</td>
<td>(insuf)</td>
<td>0.0000</td>
<td>608.31</td>
<td>608.31</td>
</tr>
<tr>
<td>Total Demand Pila</td>
<td>6749.9</td>
<td>(insuf)</td>
<td>1.0000</td>
<td>1.394E+05</td>
<td>1.394E+05</td>
</tr>
<tr>
<td>Total Demand VSG</td>
<td>1.343E+05</td>
<td>(insuf)</td>
<td>1.0000</td>
<td>2.674E+05</td>
<td>2.674E+05</td>
</tr>
</tbody>
</table>

#### OUTPUTS

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System.Numberout</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

**Simulation run time:** 0.00 minutes.

**Simulation run complete.**
APPENDIX XXI: SIMULATION MODEL WITH REACTIVE EMERGENCY SHIPMENTS

This model is almost the same with the proactive model, except the review flow, since the sequence of decisions are different. The review flow is given in the figure below: