SYNCRON INTERNATIONAL AB

Environmental and Economic Benefits of using Multi-Echelon Inventory Control

-A Case Study

Sven Nilsson, Lina Ottoson

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Institution: Production Management, Lund University, Faculty of Engineering

Supervisor at Lund University, Faculty of Engineering: Johan Marklund

Supervisor at Syncron International AB: Charlotte Sallmén

Preface

This master thesis was conducted at Production Management, Lund University, Faculty of Engineering during the Spring of 2013. It is the finalizing part of our five years long education at Lund University at the program Industrial Engineering and Management. The 20 weeks this project lasted have been both educational and interesting.

We want to thank both our supervisors Johan Marklund at Lund University, Faculty of Engineering and Charlotte Sallmén, Syncron International AB for making this thesis possible.

We want to thank Charlotte Sallmén for her help during this thesis, and for always being there for us if we have had any problems or ideas we wanted to discuss. We also want to thank Charlotte for extracting the data we needed from Syncron's data-base. Finally, we want to thank her for reading our thesis and for giving insightful comments which increased the quality of this thesis.

We want to thank Johan Marklund for his expertise in the subject of this master thesis. This helped us to perform a more advanced analysis and also ensure that it was valid. Johan have been an invaluable resource when we wanted to discuss the simulations or the data analysis. His great knowledge in this area was very useful and also contributed to a huge learning opportunity for us, which was one of the best things with this project. As a last aspect Johan have thoroughly read our thesis to ensure the quality of it.

Last but not least we want to thank Syncron International AB, Lantmännnen Maskin AB and all other involved parties for giving us the opportunity to perform this master thesis.

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Sven Nilsson Lina Ottosson

Summary

This master thesis evaluates the benefits of using multi-echelon control instead of single-echelon control of a multi-echelon inventory system. The multi-echelon inventory system studied in this thesis is a one-warehouse-multiple-retailer inventory system. *Multi-echelon inventory control* is defined as a method to optimize the inventory system by taking the interdependencies between different stock locations in the system into consideration. *Single-echelon control* on the other hand is defined as optimizing each stock point in isolation and disregarding the interdependencies that exists. There has been extensive research in this area, and the fact that large potential cost reductions exist is well documented. However, little research has been performed to evaluate the environmental benefits that can be rendered by implementing multi-echelon inventory control.

The purpose of this master thesis is to evaluate the environmental and economic benefits of using a more advanced multi-echelon control method in a real case instead of the commercial single-echelon control method currently used. The hypothesis is that by fulfilling the fill-rates better, the amount of emergency orders can be reduced significantly, and by this also the total CO_2-emissions can be reduced.

The company studied is Lantmännen Maskin AB (LM) who provides their retailers in Sweden, Norway and Denmark with spare parts for agricultural machinery. The methodology used have been that of an operations research study where both mathematical models and simulations have been used. As a base model a commercial single-echelon model currently used at Lantmännen Maskin has been used, called *SCP* in this thesis. This model was compared to a more sophisticated multi-echelon model developed at Production Management, Lund University, Faculty of Engineering by Berling and Marklund (2012;2013), called *MEM* in this thesis. The approach of the project can be divided into five steps; first the data from the case company was gathered. Secondly, an existing simulation model was extended to fit the needs of this study. Thirdly, a stratified sampling was performed on the gathered data to find a representative sample of the case company's items. Fourthly, the inventory system was optimized with

SCP and MEM respectively. Finally, the results from the SCP-model and the MEM-model was simulated and compared.

The results show that the average fill-rate was increased with 8.3% from 92.0% to 99.6%, the holding costs went down with 18.1% and the CO_2-emissions were reduced with 57.0%. Further, the MEM model shows to be more consistent on achieving target fill-rate, whereas the SCP model varies a lot and delivers some fill-rates which are well below target and some that are above.

Sensitivity analysis of the results concerning the CO_2-emissions shows that for this case study the emergency orders sent by air do not affect the system very much. The reason is that the emergency transports by air are very few compared to the ones sent by truck. To really examine the benefits that could be achieved with the MEM model compared to the SCP model, a modified case set up was investigated where all emergency orders were assumed to be sent by air. In this case the reduction of CO_2-emissions can be as high as 90%. Another important aspect found during this thesis concerning the CO_2-emissions is that certain item attributes can make some items affect the CO_2-emissions of the whole system in a non-proportional way. Two important factors were found, weight and mean demand. All CO_2-emissions are linearly dependent on the weight, and consequently, this is a very important factor. But the second factor has even more influence. The reason for this is that if the mean demand for an item is high compared to other items then this item can have relatively many emergency orders even if the fill-rate is high. This was found during the study where one item, which had a high fill-rate, emitted CO_2-emissions equivalent to 68% of the CO_2-emissions of all of the studied items.

Consequently, the conclusion from the results is that implementing the MEM model instead of the SCP model will reduce the environmental impact. Further, there are other aspects which are important to consider; firstly the MEM model will be more consistent on achieving target fill-rates than the SCP model, secondly the reduction of CO_2-will be greater in a system using air transport for emergency orders instead of land transport, and finally, the weight and mean demand are important aspects to consider if the environmental impact is to be reduced.

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1. Introduction

This chapter will introduce the reader to this master thesis and the subject of multi-echelon inventory control. The background to the problem, the purpose and the delimitations of this master thesis are found together with an introduction to the initiating firm for this thesis project, Syncron International and the case company, Lantmännen Maskin AB.

1.1 Background

Inventory systems which include more than one level are in the inventory management literature called multi-stage or multi-echelon inventory systems since they consist of several stages with interlinked inventories. Examples of multi-echelon inventory systems can for instance be a system with several suppliers and one central warehouse, a system with one central warehouse and several retailers or a combination of the two.

The type of system studied in this master thesis is a distribution inventory system which means that the flow of products is divergent. More precisely the system is a one-warehouse-multi-retailer system, see *Figure 1*.

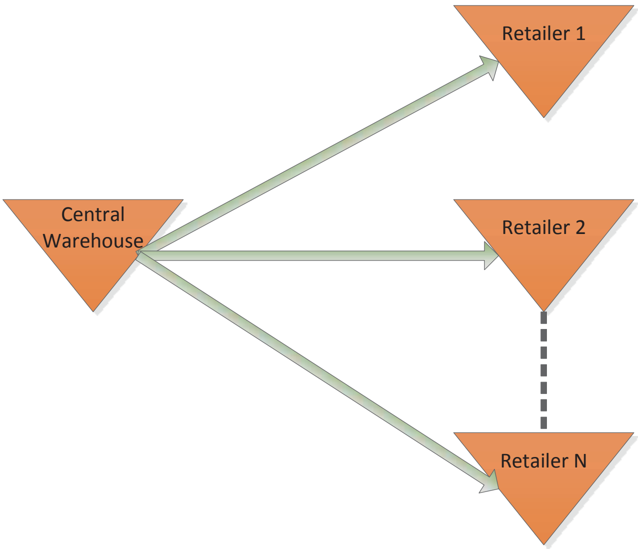


Figure 1. Illustration of a one-warehouse-N-retailer inventory system.

For ease of presentation, the term multi-echelon inventory system will from now on be synonymous with a one-warehouse-multiple-retailer system. For controlling the multi-echelon inventory system, two approaches are considered in this thesis, referred to as single-echelon control and multi-echelon control. Single-echelon control is a method where the interdependencies between the different stock locations are not taken into consideration and each inventory location is controlled independently of all the other locations. Multi-echelon inventory control on the other hand incorporates the interdependencies and optimizes the whole system at once. Consequently, there are many different methods which can be referred to when single- or multi-echelon inventory control is considered.

This master thesis will investigate the benefits that can be gained by controlling a multi-echelon inventory system in a more sophisticated way, i.e. multi-echelon control at the chosen case company *Lantmännen Maskin AB*. The focus will lie on both costs and emissions from freight where the latter is a new environmental point of view for the type of system studied in this project. An interesting observation from an environmental perspective is that when stock-outs occur at the retailers this leads to so called emergency shipments sent from the central warehouse. An emergency shipment is a transport which has the sole purpose of delivering the goods to the customer as fast as possible. Because of this, the mode of transportation or the transportation network used needs to be faster than for a regular transport. This means air transport if the location is not possible to reach by truck in one day or a dedicated truck or dedicated transportation network for more adjacent locations. Both the costs and CO_2-emissions are typically higher for these emergency transports compared to the regular transports. (Jetpak, 2013; NTM, 2010; NTM, 2011; Posten, 2013b) This master thesis will evaluate the potential at Lantmännen Maskin to decrease the costs and environmental impact of using a more precise multi-echelon inventory control method in contrast to the commercial single-echelon control method currently used.

1.2 Syncron

This master thesis is performed at Syncron International, a global supply chain management software company with offices around the world. (Syncron 2013a) The company was founded in 1990 with the headquarter situated in Stockholm, Sweden.

Syncron focuses on supporting multi-national corporations in manufacturing and distribution industries, and to help their customers improve their competitiveness and financial performance. (Syncron, 2013b) The company supplies consultancy services and ERP-independent supply chain software solutions for *global inventory management*, *global order management*, *global price management* and *master data management* to their customers, *see Figure 2*. Supply chain *Software-as-a-service* (SaaS) solutions through the "cloud" can also be delivered by Syncron as an alternative. Several industries can be found among the clientele, e.g. companies within mining and construction equipment, industrial equipment, transportation, and consumer and industrial products. (Syncron 2013a)

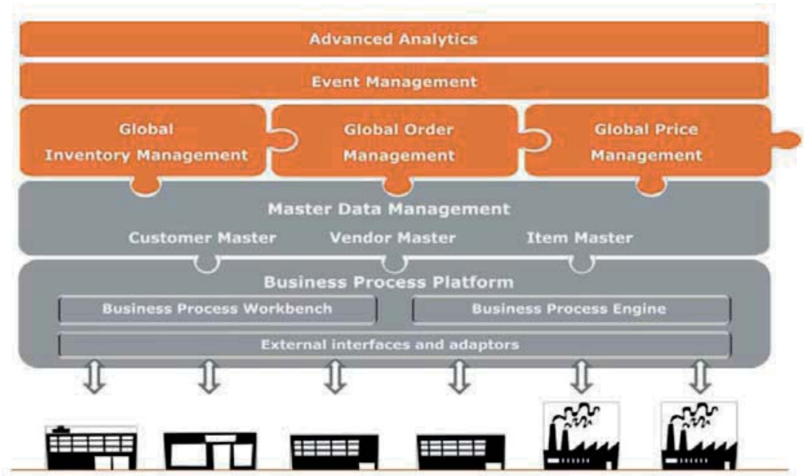


Figure 2. Overview of the service provided by Syncron. (Syncron 2013a)

1.3 Case company introduction

The case company in this master thesis is Lantmännen Maskin AB (LM). They are a subsidiary of Lantmännen AB. Lantmännen Maskin is selling agricultural machinery such as tractors, combine harvesters and tools to farmers in Scandinavia. LM also delivers spare parts for the equipment they sell. It is the inventory control of these spare parts that is considered in this project.

The turnover for LM in 2010 was 4 314 million SEK and the total number of employees was 866. The headquarter is situated in Malmö in Sweden where also the central warehouse is located. (Lantmännen Maskin AB, 2013a)

LM is one of Syncron's customers using their Global Inventory Management (GIM) solution, currently without any of its multi-echelon functionality. To determine the reorder points and order quantities in the inventory system, the single-echelon module in the Syncron software, SCP, is used. (Hersner, 2013a)

SCP is the single-echelon control model used as a benchmark in this master thesis. From now on when referring to a single-echelon inventory control model, it will be synonymous with the solution at Lantmännen Maskin available in Syncron's software, SCP. Even though Lantmännen does not use the multi-echelon module they are eager to find out if a multi-echelon control approach can improve their performance.

In Sweden LM's distribution network consists of 50 retailers, see *Figure 3*, most of them owned by Lantmännen. In fact, in Sweden only Kalmar Lantmän is externally owned, but in Norway and Denmark most retailers are externally owned. (Lantmännen Maskin AB, 2013a)

The regular transportation mode for spare parts is by truck with a transportation time between one and two days, depending on the location in Sweden. Emergency orders are delivered before 7 am next day at all the retailers and if transportation by land is not feasible, air transportation is used. (Hersner, 2013a)

Lantmännen was selected since they fitted the requirements for the project well and was interested in the results. Moreover, there existed a well established relationship established between Lantmännen and Syncron which simplified the decision further.

Figure 3. The location of Lantmännen Maskin AB's retailers in Sweden. (Source: http://www.lantmannenmaskin.se/sv/Om-oss/Har-finns-vi/)

The environmental policy at Lantmännen states that they should contribute to a sustainable society. They have the following action plan to achieve this (translated from Swedish):

- Teach the organization and our customers to choose and use our products in an environmentally friendly way.
- Have a good relationship with the authorities and other stakeholders to make sure that laws and other obligations always are followed.
- Continuously overlook and improve our resource utilization, such as energy, chemicals and materials.
- Continuously improve the knowledge of our impact on the environment and spread it throughout the organization.
- Work closely with our suppliers and convince them to work towards lowering their impact on the environment and resource usage.

(Lantmännen Maskin AB, 2013b)

1.4 Problem identification

The possibility to reduce inventory levels and achieve target fill-rates[1] by using multi-echelon inventory control methods instead of single-echelon inventory control methods has been evaluated in several research papers, for example, by Berling and Marklund (2012; 2013). Reduction of inventory and better fulfillment of target fill-rates evidently leads to economic benefits but there might be more to this than what meets the eye. With the global warming on the agenda and because of restrictions on energy consumption, such as the Emission Trading Scheme, more companies are starting to show interest in being "environmentally friendly". An interesting point to consider is therefore the possible

[1] Service level - The service level can be defined in the three following ways: **S1** = probability of no stock-out per order cycle, **fill-rate** (i.e. S_2) = fraction of demand immediately satisfied from stock on hand, **ready rate** (i.e. S_3) = fraction of time with positive stock on hand. (Axsäter 2006, p. 94)

environmental benefits that could be rendered by using a multi-echelon inventory control method that is better at meeting the specific target service levels than the current system used.

An obvious issue for LM is when there are shortages of critical items, for instance spare parts, at an inventory location. When there are shortages of critical items these are usually covered via emergency shipments, a faster and more expensive mode of transportation than the regular transports. Usually, the costs of not using emergency shipments when a shortage has occurred are much higher than to use them and sometimes several times more expensive. The cost of a stock-out varies for LM since there are many possible scenarios for this to happen. One of the most expensive scenarios is when, for instance, a combine harvester brakes down in the middle of the harvesting season. The cost for the farmer can then be 800 000 SEK per day. (Hersner, 2013a)

The problems to investigate can be summarized in the following way:

- What are the combined benefits which can be achieved by using multi-echelon inventory control at Lantmännen Maskin AB, concerning both economic and environmental measures?
- What economic and environmental effect has the emergency orders at Lantmännen Maskin AB in comparison to the total cost and environmental impact of the whole spare parts inventory system?

1.5 Purpose

The purpose of this project is to evaluate the environmental and economic benefits of using more advanced multi-echelon inventory control instead of the current single-echelon inventory control method at Lantmännen Maskin. Particularly, the impact that improved fulfillment of fill-rate targets can have on reducing emergency orders, their associated inventory holding costs and transportation CO_2-emissions will be evaluated.

1.6 Delimitations

The study will be restricted to one case company, Lantmännen Maskin AB, and hence, the items evaluated in the analysis will come only from this company's product portfolio. Not all items will be investigated, instead a sample of items representative for the entire population of products will be analyzed. The reason for this is that the number of items, about 120 000, is too large to make it possible to simulate all of them in the time frame of this master thesis.

Only retailers which are internally owned will be studied since these are the ones which are using Syncron's software. This delimits this project to only study retailers in Sweden and to exclude the retailer in Kalmar, Kalmar Lantmän, which is an externally owned retailer.

The parameters which will be compared between the multi-echelon control method and the SCP model are total cost and environmental impact in terms of CO_2-emissions; the latter will be carefully defined in the theory part of this thesis, *Chapter 4.5*. The comparison of the single-echelon control model and the multi-echelon control model will be performed using discrete simulation in the software Extend, version 6.0.8. Only the internal flows in the inventory system will be evaluated concerning cost and CO_2-emissions. Essentially this means that the flows between the outside suppliers and the central warehouse are disregarded in the matter of costs and CO_2-emissions. The reason for this is that these flows are not controlled by Lantmännen and that the information, for instance regarding the CO_2-emissions, is not available at Lantmännen.

1.7 Target group

The target group of this master thesis is primarily managers and other employees at Syncron International and Lantmännen. Secondly, the target group of this report is logistics professionals and master's students which have basic knowledge in inventory management and wants to broaden their view of multi-echelon inventory control, and the benefits it may bring.

1.8 Structure of the report

This section will introduce the report outline and explain where in the report different subjects are covered. Reading all chapters is not required to fully understand the results of this master thesis project. Depending on the reader and what intentions one has, different chapters will be of more or less importance. However, it is recommended for all readers to start reading *Chapter 1* since this chapter will give an introduction to this thesis and its purpose, delimitations and to the case company. Below three bullet points are displayed which will act as reading guidelines:

1. If only the results are of interest it is recommended to read *Chapter 8*. If the reader after reading this chapter wants further thoughts and analysis of the results also *Chapter 9* should be read.
2. The reader which is more interested in the theory behind this master thesis should read *Chapter 4*, which contains all the theory. If the reader also wants to learn how the theory was used to perform the project *Chapter 5, 6* and *7* are recommended.
3. Finally, if the purpose of the reader is to fully understand the methodology of this master thesis and to make sure that it has credibility, *Chapter 2* is recommended to read. After reading *Chapter 2* it can be interesting to continue on with *Chapter 5, 6* and *7* to follow up that the actions described in the methodology chapter are fulfilled throughout the project to ensure credibility.

The three different reading scenarios described above will of course not fit all readers, and therefore a combination of these can very well be a good idea. For the target group which contains of managers and employees at Syncron the first bullet point is recommended to start with. By going through this step the results and their implications will be revealed. If the reader wants to learn more about this project after reading the first bullet point, one can continue with the second or third bullet point. For logistics professionals and master thesis students a different approach can be of interest. They maybe want to read bullet point 2 first to learn more about the theory and then continue on to bullet point 1 or 3 depending on their own personal preference.

A brief summary of each chapter is found in the flow chart on the next page.

Chapter 2 Methodology

- *This chapter describes the methodology of this master thesis. Firstly, the general approach used in an operations research study is described. Secondly, this approach is modified and extended to fit the particular requirements of this study. The three concepts of validity, reliability and objectivity are also described and how this thesis incorporates them to ensure that they are thought of in every step of the project.*

Chapter 3 Literature study

- *This chapter will give an overview over different multi-echelon control models found in literature and evaluate the suitability of use in this master thesis. The models found will especially be evaluated with three criteria in mind; the computational efficiency for large problems, their applicability to real life inventory systems and their performance compared to single-echelon control. The approach developed by Berling and Marklund (2012; 2013) will be used as a base model since it is already implemented in Syncron International's software.*

Chapter 4 Theoretical framework

- *This chapter will present the theoretical framework on which this master thesis rests. At first an overview of multi-echelon inventory systems and how it differs from single-echelon systems will be described. After this introductory part of the theory a brief explanation of different tools for input-data analysis will be demonstrated. Subsequently, the chosen model for multi-echelon control is explained in detail. Finally, the theoretical framework used to determine the environmental impact of the inventory system analyzed in this project is described.*

Chapter 5 Data analysis

- *This chapter will describe the analysis conducted on the data used for the Excel model and the simulations. The data from Lantmännen was extracted from Syncron's data base according to the delimitations set in this project. Furthermore, a sample of 106 items were selected through stratified selection from the entire range of products. Subsequently, distribution fittings were done for these articles to find suitable distributions matching the historical demand for each item. The relevant data about CO_2-emissions was gathered from the transportation companies used by Lantmännen and from the data base of the Network for Transport and Environment, NTM.*

Chapter 6 Simulation model

- *This chapter will describe the design of the original Extend simulation model and the different blocks and assumptions it is built upon. Further, the changes made to the model to incorporate emergency orders are explained followed by some tests done to validate the reconstructed model.*

Chapter 7 Simulations

- *This chapter describes how the simulations were performed in this Master Thesis. At first, the approach to determine a valid simulation time is described. After that the input data to the simulation model and how the simulations were performed is communicated. Finally, the output data and how the uncertainty is handled in the model are discussed.*

Chapter 8 Results and analysis

- *This chapter describes the results from the study and the analysis of these will be presented along the way. First, the simulations of the inventory system with the actual lead-times are reported. After this, the results are deeply analyzed and different findings are discussed. Thirdly, the results from the simulation with the lead-times currently used in the SCP model are reported and compared to the results for the actual lead-times. Finally, the special aspects of Lantmännen's inventory system and how it differs from other companies are discussed.*

Chapter 9 Conclusions and discussion

- *Initially, in this chapter the conclusion drawn from the results will be demonstrated and reconnected to the purpose of this master thesis. Secondly, a discussion around the results is performed. Especially subjects that can affect the result or be affected by the results are included. The contributions provided from this project are also explained in the discussion. Finally, a brief discussion around suggestions for future researches is given.*

2. Methodology

This chapter describes the methodology of this master thesis. Firstly, the general approach for an operations research study is described. Secondly, this approach is modified and extended to fit the particular requirements of this study. The three concepts of validity, reliability and objectivity are also described and how this thesis incorporates them to ensure that they are thought of in every step of the project.

2.1 Scientific approach

Initially, when a new project is about to start it is important to reflect over its purpose and objective to be able to choose a proper method of study. Three different approaches, *Explorative*, *Descriptive* and *Normative studies*, are further explained in *Chapter 2.1.1*. Depending on what kind of project that is conducted different choices have to be made when it comes to the decision about what kind of information to collect and how to collect it. In *Chapter 2.1.2* the difference between *Quantitative* and *Qualitative studies* will be discussed and in *Chapter 2.1.3 Primary* and *Secondary data* is defined.

2.1.1 Explorative, descriptive and normative studies

The choice of what type of study to perform can, to a great extent, be dependent on the amount of knowledge within the research field. When there is little knowledge in a studied area and more understanding is needed an explorative, investigative, study fits well. (Björklund and Paulsson, 2003, p.63) An explorative study investigates a new field or phenomenon. When several explorative studies have been performed enough knowledge of the field are available so that a study can be of a descriptive nature. (Karlsson, 2009) Consequently, if there is basic knowledge and understanding and the aim instead is to describe the field, a descriptive study can be chosen (Björklund and Paulsson, 2003, p.63). A descriptive study describes the whole studied system more thoroughly and lays the ground for more advanced research. When the field has been explored enough with explorative and descriptive studies the next type of study is a normative study. A normative study uses the knowledge from earlier research of the field to try to forecast what will happen in different situations of the system. Since a normative study can foresee the behavior of the system it can also act as guidance to increase the performance of the system studied. (Karlsson, 2009)

Scientific approach chosen in this master thesis

The scientific approach in this master thesis can be seen as a mix with elements from all three approaches described above. The reason for this is that the study consists of many different components which make it possible to take the research to a higher level regarding some aspects than on others. Because it is a case study the results will primarily be representative for the studied case company and not necessarily for any other company. Generalizing them to other companies requires a careful assessment of the similarities and differences between these companies' distribution systems. However, the results will give an indication and illustration of what the environmental impact of the emergency orders on the total transportation system can be. Consequently, this part will be more of a descriptive study even though attempt will be made to create guidance. On the other hand, some parts of the study will be normative since the simulation model makes it possible to understand the interaction of the emergency orders and the regular orders in a complete way. By this, it is possible to explore and understand these aspects, and consequently, not only describe but foresee the results of the real system. The analytical multi-echelon model is normative.

2.1.2 Quantitative and qualitative studies

Quantitative studies comprises information which can be valued or measured in a numerical way, while qualitative studies increases the understanding for a specific subject, situation or occasion. Because it is not possible to measure everything in a quantitative way, exclusively using this method may be limiting. The same can be said about the qualitative methods. The purpose of a study determines if it will be quantitative or qualitative, and hence, which methods to apply. For quantitative studies mathematical models and/or questionnaires are typically used, whereas observations and interviews are generally applied in qualitative studies. (Björklund and Paulsson, 2003, p.63)

Quantitative and qualitative studies chosen in this master thesis

This project uses a quantitative approach where a mathematical model and simulations will be used for the analysis. In addition, a qualitative study, including a literature review and interviews with people of the involved companies, will be conducted to further consolidate the results from the quantitative approach. The qualitative study is also used for data gathering and to improve the understanding of the situation to be modeled.

2.1.3 Primary and secondary data

Primary data refers to information gathered with the purpose of being used in the study at hand. It is often preferred since it will be less affected by other persons' views. It is also significant when creating understanding for a single studied subject. (Björklund and Paulsson, 2003, p. 68, 74)

In contrast to primary data, secondary data has been gathered with another purpose in mind than that of the current study. Important aspects to consider when handling secondary data are to ensure that the information still is accurate and unbiased. The original sources and the quantity of independent sources of information are also important to reflect on when for instance performing literature reviews. (Björklund and Paulsson, 2003, p. 67, 77)

Primary and secondary data chosen in this master thesis

The primary data used in this master thesis have been collected through interviews with Lantmännen Maskin and through emails and phone conversations complementing these interviews. The primary data was used to properly model the multi-echelon inventory system in the simulation environment and, particularly, to determine how emergency orders are triggered and handled at every stock point. During the interviews, guidelines for the scope of the study were discussed with Lantmännen Maskin. The parameters which should to be incorporated in the selection of the representative sample of products were also established together with Lantmännen.

The data gathered from Syncron's database is also seen as primary data since it was not processed before it was obtained. This data was analyzed in Microsoft Access and Microsoft Excel. The complete data analysis is described in *Chapter 5*.

The information obtained from the literature, company presentations and web pages is considered as secondary data. The $C0_2$-emissions are classified as secondary data since it has been processed by another party than the authors of this master thesis.

2.2 Modeling approach – general operations research study

The purpose of this master thesis was very specific as it was set up to investigate the benefits of multi-echelon control versus single-echelon control. There was already a suggestion to what model to use for the multi-echelon control since this model is under implementation in Syncron's software (GIM). The model at hand is presented in Berling and Marklund (2012; 2013). Further, the aim of this study was to find out what the benefits of implementing multi-echelon inventory control at the chosen case company could be. To explore the benefits of using multi-echelon control, one option would be to compare the current system at the case-company to that of another company that instead uses multi-echelon control. As for now no data from such systems is available to the authors of this master thesis or the host company Syncron. Consequently, it is not possible to evaluate the inventory system at Lantmännen and benchmark it to another system which is approximately the same but uses multi-echelon control.

Another approach for this study would have been if Lantmännen already had started to use multi-echelon control of their inventory system. Then the performance of this system could be compared to single-echelon control directly in Syncron's software. Since this is not possible the remaining option is to use simulation.

Methodologically, this thesis belongs to the field of Operations Research (OR). The general approach of an OR study can be divided into six main steps which usually are overlapping, see for instance Hillier and Lieberman (2001, p. 7-23):

1. Define the problem and gather data.
2. Represent the problem by formulating a mathematical model.
3. Derive solutions to the problem by developing a computer-based procedure.
4. Test and refine the model as needed.
5. Prepare the ongoing application of the model assigned by management.
6. Implement.

2.2.1 Define the problem and gather data

The first step in the general approach includes a study of the concerned system and development of a relevant problem statement which later on will be scrutinized. Matters like appropriate objectives, constraints on what can be done, time limits for the decision making etc. will be determined in this step. Since the problem definition affects what kind of conclusion will be attained in the project, it is a crucial process. Gathering relevant data is usually required both for a more accurate understanding of the problem and to obtain required inputs for the upcoming model. (Hillier and Lieberman, 2001, p. 7-9)

2.2.2 Represent the problem by formulating a mathematical model

The second step involves reformulation of the problem to a more convenient form for the analysis by constructing an appropriate mathematical model. A suitable approach to apply when developing the model is to start with a simple version and then move towards a more complex model through incremental steps. (Hillier and Lieberman, 2001, p. 10)

2.2.3 Derive solutions to the problem by developing a computer-based procedure

In this step a procedure for deriving “near optimal” solutions for the earlier stated problem is generated from the model. This is in general accomplished by using a computer-based procedure and applying a standard algorithm of OR by using an already available software package to effortlessly model the problem. (Hillier and Lieberman, 2001, p. 14)

2.2.4 Test and refine the model as needed

A large mathematical model in an early version generally incorporates many errors which need to be detected. Hence, this phase builds on meticulously testing the model to find flaws which subsequently will be corrected. (Hillier and Lieberman, 2001, p. 16-17) This process is called *verification* or to ensure the *internal validity* of the model. It is important to notice that a verified model not necessarily describes the system accurately; it only indicates that the model is free from internal bugs, and behaves in the way the creators intend it to do. The process to ensure that the model describes the real system correctly, or at least sufficiently, is called validation or ensuring the external validity of the model. This process challenges the model's assumptions and can for instance consist of comparing the results of the model with real life data and to see if they correspond to each other in a satisfactory way. (Law and Kelton, 2000)

2.2.5 Prepare the ongoing application of the model assigned by management

A frequently used model is beneficial to install in a well-documented system, usually computer-based, to be able to apply the model as management has decided. The model, solution procedure, and operating procedures for implementation should be a part of this system. (Hillier and Lieberman, 2001, p. 18-19)

2.2.6 Implement

The final step of the OR approach is the implementation of the solution or system. It is significant that the OR team is involved at this stage since they are more familiar with the model and can ensure that the model solutions are correctly translated to an operating procedure. Hence, they can correct any undiscovered errors in the solution. If significant deviates from the primary assumptions are observed, the model should be checked to decide if any changes of the system are required. (Hillier and Lieberman, 2001, p. 20-21)

2.3 Modeling approach – this master thesis

The approach for conducting an operations research project as described by Hillier and Lieberman (2001) is quite general and intended to be applicable to any operations research study. This master thesis will not cover all the steps in this approach, primarily step 5 *"Prepare the ongoing application of the model assigned by management"* and step 6 *"Implementation"* will fall outside the scope of this master thesis. Since every study is unique this general method is not sufficient to fully describe the approach used in this master thesis. It will, however, be used as a frame work, which is modified and extended to fit this thesis project. The next section describes this modified methodology used for this thesis.

2.3.1 Define the problem and gather data

The problem definition for this master thesis was initially developed in cooperation with Syncron, as the company had a need to further evaluate the environmental and economic benefits of using multi-echelon control.

Initially, in the first step, the problem definition was established analogously to the purpose of the project stated by Syncron and other involved parties. Subsequently, required theory was collected to increase the understanding of the problem, and hence, further deepen the project description with problem identification, purpose and delimitations. The theory was foremost gathered through literature reviews, explained in *Chapter 3*.

The data used in this project consists of primary and secondary qualitative and quantitative data. The *data* gathered through interviews with Lantmännen and Syncron is primary data. The quantitative data obtained from Syncron is also primary data since it has not been processed for another purpose than this master thesis. This data was obtained from Syncron’s database according to the parameters specified in *Appendix A*. The data obtained from Posten, Jetpak and Lantmännen is secondary data since it has been processed and used for other purposes than this project.

2.3.2 Analyzing data and find a representative selection of items to study

This project has one issue which an operations research study described by the general approach does not usually have. Normally, the focus is on developing a mathematical model which can optimize the studied system. This means that the type of items studied are of minor importance compared to the fact that the model actually optimizes the system correctly. This thesis focuses not on the development of a mathematical model, even if a suitable model needed to be chosen, but on the evaluation of a real life inventory system.

The amount of items that the case company carries is vast. Hence, evaluation of all items through simulations is not possible within the stated time frame of this thesis project. Therefore one of the challenges was to select an appropriate sample of items. This sample needed to be large enough to be representative for the inventory system and small enough to fit into the scope of this project.

Stratified selection

A common approach, for instance when selecting people for interviews in election poles, is to use random selection of individuals since this ought to describe the population correctly if enough individuals are chosen. This approach is not necessarily the best way if the sample is small. The selection in one particular sample may then be skewed. One way to prevent this is to use a so called stratified selection where important parameters are taken into consideration in the selection. This will ensure that they are represented in the final sample in a large enough quantity. (Bryman and Bell, 2011, p. 719)

Consequently, a stratified selection is a suitable approach for choosing an appropriate sample of the data obtained from the case company. The methodology aims at picking units from a defined population to a random sample. The population is divided into categories, called strata, on a pre-determined basis. (Bryman and Bell, 2011, p. 719)

In stratified selection each member of a population can be chosen with the same probability as every other member of the same population. This is because the methodology is built on the principle of randomness simultaneously as the selection is done according to certain properties for the items. The number chosen from each "strata" shall also be in direct proportion to the population of all items. An advantage of stratified selection compared to a standard random selection is that one can ensure to keep some control over the sample and that essential factors are included and in proportion to how they occur in the entire sample. (Denscombe, 2011, p. 33-34)

Decide upon important parameters

Before carrying out the stratified selection the parameters used to divide the data into strata were chosen. The parameters should be of importance to the subject studied to ensure that the sample will be representative for the whole population of items, and the issues that the project aims to study. In this project the environmental impact, i.e. emissions from emergency transports, is an important factor, and hence, needs to be represented sufficiently in the selected sample. Another important factor is the standard deviation divided by the mean since this is an indication of how difficult the item is to control from an inventory perspective. Since the economic aspect is important the value of the items is a significant parameter, because more expensive items will tie up more capital. Of course, the important parameters can differ significantly but the key here is to identify the most important parameters that need to be represented in the data sample to make it representative for the whole population.

The full data stratification and input-data analysis will be described in *Chapter 5*.

2.3.3 Represent the problem by formulating a mathematical model and derive solutions to the problem by developing a computer-based procedure

To formulate a model and derive a computer-based solution is a challenging step. This master thesis focuses on evaluating the possible environmental and economic gains of applying a specific multi-echelon inventory control method. Hence, deriving a new model is outside the scope of this project. The approach will instead be to perform a literature review to see what different types of models are available in the literature that fits this project.

Syncron has already implemented a multi-echelon control in their software system, based on the method by Berling and Marklund (2012; 2013). Consequently, this model will be seen as a base model which all reviewed models in the literature review will be compared to.

Literature review

Performing a literature review is not just good practice but a necessity to verify that this master thesis will not just repeat what has already been done. (Höst et al., 2006, p.59)

The first part of the literature review will be on the subject of inventory control and especially multi-echelon inventory control to give a deeper understanding of the subject. The second part will go over which models are published in literature on coordinated control of multi-echelon systems. Recently published master theses on the subject and especially at Lund University, the Faculty of Engineering were also reviewed.

The approach for the literature review of this master thesis was to use currently published literature reviews and to screen the reference list of Berling and Marklund (2012; 2013) since this is the base model. The literature reviews included are supposed to deal with the subject of inventory management and multi-echelon inventory control in particular. From these literature reviews possible models were identified and reviewed to see if they were more suitable than the model by Berling and Marklund (2012; 2013).

The literature review is described in full in *Chapter 3*.

Selection of the mathematical model

To fit this project the mathematical model used needed to fulfill some requirements. It needs to use a (R,Q)-policy[2], be able to handle any type of

[2] (R,Q)-policy – Orders are triggered as soon as the *inventory position* is below or at the reorder point R. The size of the order will be a batch of Q units if this is enough to reach above R, otherwise the order size will be the smallest number of batches of size Q required to reach an inventory position above R. (Axsäter 2006, p. 88) The inventory position is defined as: inventory level + outstanding orders – backorders (Axsäter 2006, p. 45)

demand at the retailers, and be computationally fast enough for large real life problems. These requirements originates from Lantmännen and ultimately from Syncron since their system uses a (R,Q)-policy for inventory management. The model later selected for this project is developed by Berling and Marklund (2012; 2013) and is described in *Chapter 4.4.2*. The differences between the two articles are the demand assumption at the retailers and how the model solutions are obtained. In Berling and Marklund (2012) a normal approximation of the demand is used and in Berling and Marklund (2013) demand is assumed to be compound Poisson distributed. Since no other model with better fit to the multi-echelon inventory system studied in this project could be found, the model by Berling and Marklund (2012; 2013) was chosen. This model fits the required conditions and also has a broader aspect compared to other models, see the literature review in *Chapter 3*. This is because it handles both compound Poisson demand and normal demand at the retailers in the same system with documented results, which no other models currently available in literature known to the authors do. The model is computationally fast for all types of demands and structures of retailers. However, the compound Poisson assumption, which is suitable for low and lumpy demand patterns, may by definition be computationally challenging for certain demand processes. If the compound Poisson assumption is too computationally exhausting the normal approximation can be used instead. The model described in Berling and Marklund (2012; 2013) will be denoted MEM in this report.

These findings above together with the fact that Syncron already has cooperation with the division of Production Management at Lund University, Faculty of Engineering, and has started to implement the model, consolidated the decision further. The current model for uncoordinated control, SCP, implemented by Syncron at the case company is the reference point for this study.

2.2.4 Test and refine the model as needed

The sample items were chosen according to stratified selection, *Chapter 2.2.1,* and the input data analysis was performed by the use of “StatFit” which is a module for distribution fitting in Extend. The data on the selected items was transformed to the right format before “StatFit” would accept it; this data processing was performed in Microsoft Excel and Access. The “StatFit” module was in essence used to determine if the normal distribution was a good fit for the data with coefficient of variation (variance divided by the mean) below 1. It was also applied to decide which compound Poisson distribution was adequate for the demand with a coefficient of variation over 1. When the sample size for any of the retailers of an item was too small, i.e. less than 10 observations, and the coefficient of variation was over 1, an empirical compound Poisson distribution was used.

In *Chapter 5* a total description of how the input data analysis was performed can be found.

Environmental impact in the simulation model and reality

The main contribution of this thesis is the evaluation of the environmental impact that the use of more precise multi-echelon control could have on an inventory system. To be able to fully assess this, the drivers of environmental impact concerning the multi-stage inventory system at Lantmännen needed to be explored. To review the inventory system in the light of environmental impact, an interview was performed with Lantmännen, see *Appendix B.*

The tests of the multi-echelon inventory control model, MEM, and the single-echelon inventory control model, SCP, were performed in simulation software called Extend 6.08[3]. A basic model used for research purposes of multi-stage inventory systems was already available at the division of Production Management at Lund University, Faculty of Engineering. This model has been used in earlier research and master theses at the division. Consequently, the internal validity of the initial model is high which increases the validity of the results from the same model found in this thesis. However, this basic model cannot handle emergency orders, and hence, this feature was added to the model. Developing the current model and fit it to the emergency orders was one cornerstone of the project. To ensure the validity of the final results it was

[3] http://www.extendsim.com for further information of the simulation software used.

very important that this step was correctly performed. This process consisted of three steps. First, the policy for placing emergency orders was implemented in the current model. Secondly, the model was verified to see if the new implementation behaved as it was supposed to. Finally, the results from the verified model, when using the original reorder points for several items, were validated with real life data received from Lantmännen. This was done to ensure that the results were realistic. If something conspicuous would have been found in the implementation of the emergency orders a reevaluation of it would have been done and steps two and three would have been repeated.

The simulation model and the changes made are described in *Chapter 6*.

When the simulation model was verified, the multi-echelon control model was compared to the current single-echelon control model with respect to costs and environmental impact. The procedure was as follows:

1. Determine the reorder points with the multi-echelon model, MEM, and the current single-echelon model, SCP, respectively. Both calculations will be based on the same mean and standard deviation of the demand.
2. Simulate the system with the two sets of reorder points
3. Evaluate the results for each mode of control and compare

The simulations are described in *Chapter 7*.

2.3 Legitimacy of this master thesis

To be able to substantiate the legitimacy of the results and conclusions made from this master thesis three aspects were thoroughly monitored, namely validity, reliability (Höst et al., 2006, p.41-42) and objectivity (Björklund and Paulsson, 2003, p.59).

2.3.1 Validity

The validity of a study describes how the empirical concept and its measurements correspond to the theoretical concept. A common way of defining validity is to check if the studied object actually measures what it is intended to measure. If the validity can be questioned the entire research can be challenged. (Rosengren and Arvidson, 2002, p. 195-196) Questionnaires and interviews can provide improved validity through clear and objective questions. (Björklund and Paulsson, 2003, p.60)

Validity of input data
A significant part of the analysis in this project was based on quantitative data from Lantmännen extracted from the ERP system. This data was taken directly from the database of Lantmännen and can therefore be seen to have high validity. Further, the extractions were made by employees at Syncron who works with this database on a daily basis. The data specification Syncron used were thoroughly reviewed by Syncron before they extracted the data which further increases the validity of the data gathered, i.e. the data gathered was the data the authors wanted. The qualitative data was obtained through a literature study, involving many different and well recognized sources to increase the validity. To ensure the validity in the interview material, it was confirmed to be correct by the interviewees after the compilation of the material.

Validity of the simulation model
The original simulation model and the analytical Excel model were previously developed and tested by researchers, and hence, considered to have a high internal validity. To assure the internal validity of the expanded simulation model several tests were performed to investigate if the outputs from the simulation seemed adequate. The internal validation of the simulation model is further described in C*hapter 6.2.1*. To control the results from the analysis several sensitivity analysis were done.

Finally, the external validity was checked by controlling a handful of items with Lantmännen to see if the results from the simulations had a good correspondence with reality.

2.3.2 Reliability
Reliability describes the level of authenticity in the measurement tools, i.e. to which extent the same value will be achieved if the study is repeated. The higher the absence of random, unsystematic errors of measurement a study has the better reliability it gets. The reliability is affected by random

or temporary characteristics at e.g. the measurement tools or the measured object. For instance, a sudden change of facial expression can influence the answer of an interviewee. (Rosengren and Arvidson, 2002, p. 198-199)

Reliability in this master thesis

By preparing the interviews carefully and giving accurate instructions for the questions to the interviewees, the reliability of the interviews was increased in this project. Conducting several interviews with different involved parties at Lantmännen and Syncron was also a way of securing the reliability.

2.3.3 Objectivity

Objectivity implies keeping absence of inappropriate impact from the researchers on the results. This incorporates, for instance, things that can happen during the working process with question, formulation, concept formation and analysis. (Rosengren and Arvidson, 2002, p. 203) The objectivity can be increased by clearly motivating choices done in the study to enable the reader to form their own independent opinion of the results. (Björklund and Paulsson, 2003, p.61)

Objectivity in this master thesis

To increase the authors' objectivity, values and opinions have been kept aside throughout the entire project. Choices have been explicitly explained to further support the objectivity of the study. References and sources have also been specified throughout the report to support the objectivity of the results. Concerning the simulations and the simulation model, objectivity will not be of an issue. There might, however, be issues regarding the gathered data for the simulations. To be able to ensure objectivity in this part, decisions have been explained in detail as much as possible. If any questions of subjectivity or uncertainty regarding the choice have been raised this particular matter has been thoroughly discussed with the supervisor at Lund University, the supervisor at Syncron and Lantmännen Maskin. Consequently, many of the decisions are not the authors' alone but the result of an ongoing discussion from all stake-holders in this master thesis.

3. Literature study of coordinated control of one-warehouse-multiple-retailer inventory systems

This chapter provides an overview of different models for multi-echelon inventory control found in literature and evaluates their suitability for use in this master thesis. The models found will especially be evaluated with three criteria's in mind; the computational efficiency for large problems, their applicability to real life inventory systems and their performance compared to single-echelon control. The approach developed by Berling and Marklund (2012; 2013) will be used as a base model since it is under implementation in Syncron's software.

3.1 Literature study

Going through the literature several research papers were found that assumes complete backordering, and uses *(R,Q)-policies* to control one-warehouse-multi-retailers systems. Among these are Berling and Marklund (2012), Berling and Marklund (2013), Gallego et. al. (2007), Cachon (1999), Forsberg (1997), Axsäter et al. (1994) and Axsäter (2000). The demand distribution assumed at the retailers differs between simple Poisson demand (Gallego et. al, 2007; Cachon, 1999), compound Poisson demand (Berling and Marklund, 2013; Gallego et. al, 2007; Axsäter et el., 1994; Axsäter, 2000) and normal demand (Berling and Marklund, 2012; Gallego et. al, 2007; Axsäter, 2005).

When a multi-echelon inventory system is studied there are several components which need to be decided, either exactly or approximately. The components are the demand at the retailers, the demand at the central warehouse and the planned lead-time[4] from the central warehouse to the retailers. The research papers mentioned solve these issues differently, and consequently, perform differently when it comes to fill-rate fulfillment and computational speed. Depending on what type of demand that faces the retailers the inventory system is more or less computationally hard to optimize. One of the issues is the demand at the central warehouse. The normal approximation is generally less appropriate when the mean is small

[4] Lead-time - The time it takes from an order is triggered until the ordered items have arrived. (Axsäter 2006, p. 47)

in proportion to the standard deviation because of the large probabilities for negative demand to occur. The simple Poisson distribution may be a good fit to demand for spare parts if the customers always order one unit at a time (or the same number of units).

In Forsberg (1997) and Axsäter (2000) mentioned above, the multi-echelon inventory system is optimized exactly. These methods are fast for small problems but for larger problems the computation time will be too long. This makes them inappropriate to implement on real life inventory systems. (Berling and Marklund, 2012)

One way to solve the multi-echelon inventory system efficiently with a coordinated approach is to decompose the multi-echelon inventory system into several coordinated echelons. One article proposing to decompose a multi-echelon inventory system into several coordinated single-echelons is Anderson et. al. (1998). They use what they called an induced backorder[5] cost, β, to be able to optimize the reorder points at the central warehouse. Another research article which investigates an approximation of the induced backorder cost is Axsäter (2005). The associated β-estimate is denoted β_A^*. The approach to approximate β was later re-evaluated by Berling and Marklund (2006). Their β-estimate is denoted $\beta_{B,M}^*$. This method is, however, completely different than the induced backorder cost in Axsäter (2005). In a numerical study Berling and Marklund showed that $\beta_{B,M}^*$ is generally a better approximation than β_A^* proposed in Axsäter (2005) except for some extreme values. The method proposed by Berling and Marklund (2006) is also less computationally demanding and conceptually easier to understand, mainly because β_A^* will require evaluation of complicated derivatives (Axsäter, 2005).

As mentioned earlier, models only incorporating simple Poisson demand will not be enough since the customers of the case company order more than one unit at a time. Moreover, the case company uses (R,Q)-policies to control stock replenishments at all locations which further restricts the possible models to choose from. When it comes to computational feasibility for larger system the trade-off usually is between being exact

[5] Backorder - Demanded items that have not yet been delivered. (Axsäter 2006, p. 46)

and slow or approximate and fast. From the models found above only the models by Berling and Marklund (2012; 2013) and Gallego et al. (2007) would fit the requirements of the system studied in this master thesis. Even though the model developed by Gallego et al. (2007) could fit this study, the instance of it which is extended to incorporate compound Poisson demand is not tested in their study, and consequently, the performance of it cannot be known in advance. The performance of the model by Berling and Marklund (2012; 2013) has, on the other hand, proven to perform well during their numerical studies. This model was also developed to meet the requirements given by Syncron International:

1. Use of (R,Q)-policies
2. The reorder points should be optimized using a coordinated control
3. Realistic demand distributions should be applicable in the model, especially when the demand orders vary noticeably in size
4. Use a continuous review[6] system
5. Be computationally feasible for large systems
6. Be simple enough so that staff without any specific inventory control education will be able to understand the model

(Berling and Marklund, 2012)

Consequently, this model meets all the criteria and no other models have been found during the literature study indicating that they can fulfill all these criteria better. This model is also under implementation in Syncron's software, and hence, it is more relevant to use this model than another model if one were available. Further, the model developed by Berling and Marklund has shown good results both in their own numerical studies but also in three former master theses, namely Rasmusson and Sunesson (2009), Callenås and Lindén (2010) and Räntfors (2012). The last two of these theses were also conducted at Syncron International and performed on real life data from case companies. Therefore, this literature study concludes that the model by Berling and Marklund is, when this master

[6] Continuous review – To continuously monitor the inventory system. Orders are triggered when the inventory level descend to a certain level. (Axsäter, 2006, p. 47)

thesis was printed, the most suitable approach for modeling the multi-echelon inventory system at the chosen case company.

3.2 Validity of the literature study

To ensure the validity of this literature study only published articles, working papers and master theses were reviewed. The selection of literature consisted of both recent academic research papers and recently published master theses on this subject. To assure that relevant articles recently published are used in this literature study, two recently published literature reviews on the subject was thoroughly reviewed (Gümüs and Güneri, 2007; Kennedya et. al., 2002). The two literature reviews found are, however, not published in any of the top journals in the field. This lowers the validity, but when searching for new literature reviews these were the only ones found, and consequently, the choice was between these two or nothing at all. The choice was made that the knowledge from the literature reviews could benefit the search for other multi-echelon models and therefore they were used, even though they might have low credibility.

The overall methodology of the literature study was to start with the most recently published articles and then work backwards in the reference lists until sufficient knowledge of what had been published was achieved.

4. Theoretical Framework

This chapter will present the theoretical framework on which this master thesis rests. At first an overview of multi-echelon inventory systems and how it differs from single-echelon systems will be described. After this introductory part, a brief explanation of different tools for input-data analysis will be demonstrated. Subsequently, the chosen model for multi-echelon control is explained in detail. Finally, the theoretical framework used to calculate the environmental impact of the inventory system analyzed in this project is described.

4.1 Multi-echelon inventory systems

A multi-echelon inventory system consists of a number of stock points coupled together. This kind of system is common, for example, at companies that distribute products over large geographical areas and have a central warehouse close to the production plant and local stocking points close to the customers at diverse locations. (Axsäter, 2006, p. 187)

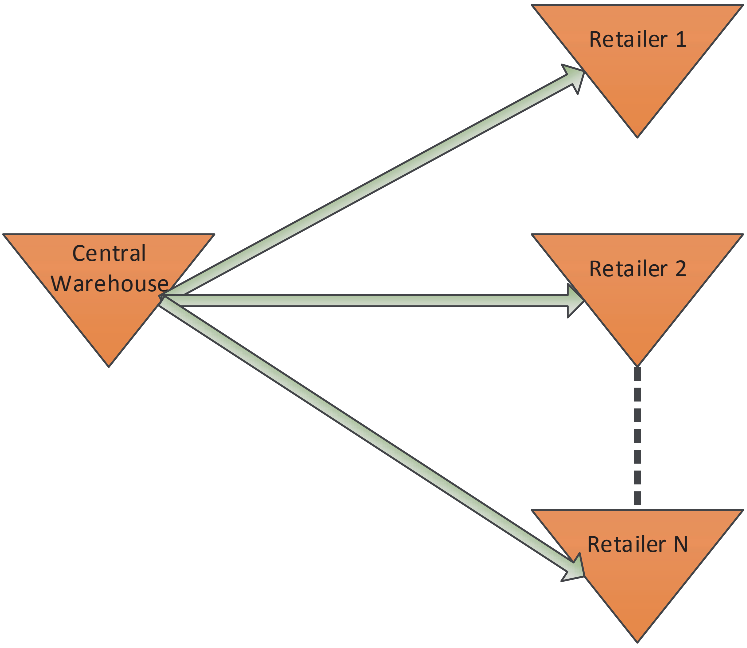


Figure 4. Two-echelon distribution inventory system.

In this thesis the focus has been on a distribution system for spare parts with one central warehouse and a number of retailers, see *Figure 4*. A general distribution system is divergent and each location has only one immediate predecessor while it can have several successors. To reach or maintain high service levels at local markets it is necessary to have the right level of goods in stock at the retailers' locations, while the purpose of the central warehouse is to support the retailers. To achieve efficient control it is necessary to use specific methods that take the connection between different stock points into consideration. The optimal distribution of the total stock in the system depends e.g. on the demand distributions, the structure of the system, transportation times and the unit costs. (Axsäter 2006, p. 187-189)

4.1.1 Modeling multi-echelon systems

Multi-echelon inventory systems are much more complex to model than single-echelon inventory systems. A way to simplify the modeling is to estimate them as multiple single-echelon inventory systems, where each single-echelon inventory system is independently controlled. A reason for doing this is that the method simplifies the control of the system and one can manage different decisions about, for example, reorder points in an easier way. The drawback is that the method does not describe the original system in an adequate way nor does it offer a good approximation of reality, i.e. service levels can seem to be better than they actually are. (Hausman and Erkip, 1994)

To control multi-echelon inventory systems, and for instance determine optimal reorder points with multi-echelon control, is much more challenging than to do it with single-echelon control. The complexity also varies depending on what type of demand the retailers face since this affects the demand that occurs at the central warehouse. (Axsäter 2006, pp. 246-247) In Axsäter (2000) the exact reorder points are determined for a multi-echelon inventory system where all installations follow (R,Q)-policies and the retailers face compound Possion demand at the retailers. Unfortunately, this method is too computationally demanding to apply on larger inventory systems with many stock points and many items.

4.2 Distributions used for modeling the inventory system

To properly understand the approaches used to model multi-echelon systems some commonly seen demand distributions will be described briefly. The distributions can be differentiated between continuous and discrete distributions. The demand which occurs at the retailer will in reality be discrete but can, if it is high-frequent, be very well approximated with a continuous distribution. For a comprehensive treatment of the subject the interested reader is referred to chapter 5 in Axsäter (2006).

4.2.1 Normal distribution – continuous distribution

The normal distribution is the most convenient distribution to use when the demand is high. The reason is its simplicity and also the fact that it is computationally fast to use. Because of the Central Limit Theorem which states that a sum of many independent random variables will approximately have the normal distribution it often offers a good fit for empirical data. However, there are warnings to be raised, especially if the normal distribution is used without a proper goodness-of-fit test to verify its suitability. If the normal distribution has a relatively small mean compared to its standard deviation there are large probabilities of negative values. This is problematic if it is used to model lead-time demand which evidentially cannot be negative. Below the density function (1) and the distribution function (2) of the normal distribution is given. (Axsäter, 2006, p.85-86)

$$\varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}, \qquad -\infty < x < \infty \tag{1}$$

$$\phi(x) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du \tag{2}$$

4.2.2 Gamma distribution – continuous distribution

When the ratio between the standard deviation and the mean is not significantly below 1 the probability for negative demand, as mentioned earlier, is quite high for the normal distribution. The gamma distribution which is always non-negative is then often a better choice, especially when modeling data that cannot be negative. Expressed in (3) is the gamma density function. The gamma distribution function cannot be expressed in closed form but it is available in common programs such as Microsoft Excel.

$$g(x) = \frac{\psi(\psi x)^{r-1}e^{-\psi x}}{\Gamma(r)}, \qquad x \geq 0, \qquad (3)$$

where $\Gamma(r)$is the gamma function, $\int_0^\infty x^{r-1}e^{-x}\,dx$, ψ and r are positive, and the gamma distribution has mean r/ψ and variance r/ψ^2. (Axsäter, 2006, p.86-87)

In *Figure 5* the gamma distribution and the normal distribution is plotted for mean 15 and standard deviation 5.

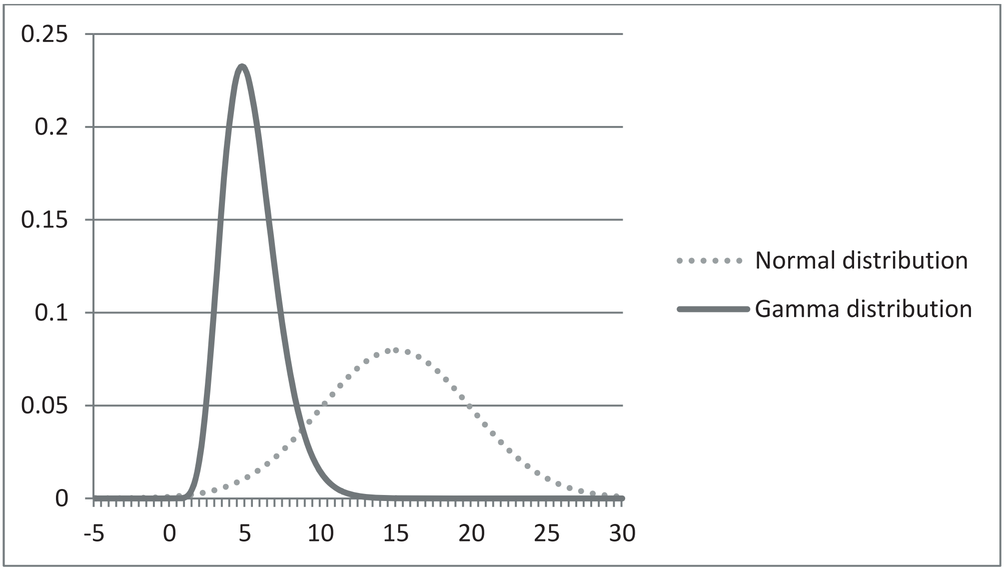


Figure 5. Comparison between the Normal distribution and the Gamma distribution.

4.2.3 Compound Poisson demand- discrete distribution

The compound Poisson process is a stochastic process where the arrival rate is analogous to a Poisson distribution; that is times between arrivals are exponentially distributed. The difference from pure Poisson is that the customers are allowed to order more than one item at the time, hence, the word compound since the compound Poisson process is made up of two different distributions.

To be able to decide the probability distribution for the lead-time demand some important results from Axsäter (2006) will be used, namely (4) and (5), whose parameters are described in *Table 1* below.

$$P(D(t) = j) = \sum_{k=0}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} f_j^k \quad (4)$$

$$\text{where } f_j^k = \sum_{i=k-1}^{j-1} f_i^{k-1} f_{j-i} \qquad k = 2,3,4 \ldots \quad (5)$$

(Axsäter 2006, p. 77-78)

Table 1. Parameters used in formula (4) and (5). (Source; Axsäter 2006, p. 77-78)

Parameter	Description
D(t)	Lead-time demand
j	The amount ordered by one customer
$\mathbf{f_j^k}$	Probability that k customers order j units
$\mathbf{f_j}$	Probability that the demand is j
$\boldsymbol{\lambda}$	Arrival rate
t	Lead-time

$\frac{(\lambda t)^k}{k!} e^{-\lambda t}$, formula (4), is the pure Poisson distribution (customers are only allowed to order one item at a time). f_j^k, is decided by recursively determining each probability for each j and k. This can be done since $f_0^0 = 1$, the probability that zero customers order zero items is one and $f_j^1 = f_j$. By summing over all possible customer occurrences and at the same time multiplying with the probability of demand size j for the different customers the probability that the demand per time unit is j is according to formula (5). For further description, see chapter 5.1.1 in Axsäter (2006).

The average demand, μ, and the average standard deviation of the demand, σ, per unit of time are determined by using formula (6) and (7):

$$\mu = \lambda \sum_{j=1}^{\infty} j f_j \quad (6)$$

$$\sigma^2 = \lambda \sum_{j=1}^{\infty} j^2 f_j \quad (7)$$

(Axsäter 2006, p. 80)

4.2.4 Negative Binomial distribution – discrete distribution

There is one special case of the compound Poisson distribution where the demand during the lead-time will follow the negative binomial distribution. This special case occurs when the compounding distribution follows the logarithmic distribution. (Axsäter, 2006, pp. 80-83)

F(x) and p(x) are illustrated below in formula (8) and (9) where s is a positive integer and $p \in (0,1)$:

$$p(x) = \begin{cases} \binom{s+i-1}{i} p^s (1-p)^i & if\ x \geq 0 \\ 0 & otherwise \end{cases} \qquad (8)$$

$$p(x) = \begin{cases} \binom{s+x-1}{x} p^s (1-p)^x & if\ x \epsilon \{0,1,\ldots\} \\ 0 & otherwise \end{cases} \qquad (9)$$

And the mean (10) and variance (11) are:

$$\frac{s(1-p)}{p} \qquad (10)$$

$$\frac{s(1-p)}{p^2} \qquad (11)$$

(Law and Kelton, 2000)

4.3 Input data analysis

An important aspect of this master thesis is to analyze demand data and to fit appropriate distributions to describe the data. The usual methodology for statistical distribution fitting can be divided into four step steps:

1. Plot the data in a histogram and hypothesize a distribution family
2. Estimate the parameters for the chosen distribution
3. Use visualization tools to initially try to confirm or disregard the hypotheses
4. Perform a goodness-of-fit test to verify the chosen distribution

(Law and Kelton, 2000)

The purpose of the goodness-of-fit test is to investigate whether the assumption that the demand data follows the chosen exact distribution is adequate. Examples of such tests are the Kolmogorov-Smirnov test and the

Chi-square test. The Chi-square is appropriate when the sample size is relatively large, i.e. at least a size of 30. (Laguna and Marklund, 2004, p.337)

Important to notice is that if the distribution is a good fit it does not mean that it is the true distribution which the empirical data originates from, all it means is that the distribution will model the empirical data sufficiently well. (Laguna and Marklund, 2004, p.332)

4.3.1 Distribution fitting

The Chi-square test

The Chi-square, χ^2, test is a statistical test built on using the χ^2-distribution to compare the theoretical probabilities of the chosen distribution with the relative frequencies for the bins in a histogram. The name χ^2 relates to the use of a test variable, see (12), following the χ^2–test distribution. The parameters for function (12) can be found in *Table 2* below. (Laguna and Marklund, 2004, pp.331-332, 337)

$$\chi^2 = \sum_{i=1}^{N} \frac{(O_i - np_i)^2}{np_i}, \qquad (12)$$

Table 2. Parameters used in formula (12). (Source: Laguna and Marklund, 2004, p.332)

Parameter	Description
O_i	The number of observations in bin i
np_i	The expected frequency in bin i
N	The number of bins

The test variable measures how suitable the fitted distribution is to model the empirical distribution from the gathered data. It is assumed that the distribution involves k parameters that have been estimated from the sample. The tested sample contains *n* observations, i.e. the sample size is *n*. The test is not appropriate to use when the sample size is below 30. The reason for this is that the fit to a continuous distribution will be worse the smaller the sample is. The hypothesis tested in the χ^2–test, the null hypothesis, is whether the assumption that the observed data follows a certain distribution can be rejected or not. If the hypothesis is not rejected the data is said to have a good enough fit to the distribution it was tested for. It is important to understand that the gathered data is not proven to follow a certain theoretical distribution through these tests. However, the tests give a possibility to conclude if one or more candidate distributions are a good fit for the sample data. (Laguna and Marklund, 2004, pp.331-332, 337)

In a test with a large sample, the test can become more sensitive to small differences between the theoretical distribution and the sample data and may reject the hypothesis of goodness-of-fit even though it is a close fit due to other means. Whereas if the sample size is small the test can only detect large differences between the sample data and the distribution it is tested against. (Laguna and Marklund, 2004, p.332)

4.3.2 Visualization

The first step to determine a distribution family for empirical data is to visualize the empirical probability density distribution function (13) in a histogram. This makes it possible to identify probable distributions which later can be tested in the goodness-of-fit test. (Laguna and Marklund, 2004, p. 328-331, 335)

$$F_n(x) = \frac{number\ of\ x_i \leq x}{n}\ for\ i = 1, \ldots, n \qquad (13)$$

4.3.3 Q-Q plots and P-P plots

When a suitable distribution is chosen and the parameters have been estimated it is good practice to create Q-Q and P-P plots of the empirical data and the fitted distribution. The Q-Q plot and P-P plot measures the difference between the empirical probability density function (pdf) and the fitted pdf as *Figure 6* illustrates. (Law and Kelton, 2000, p. 350-354)

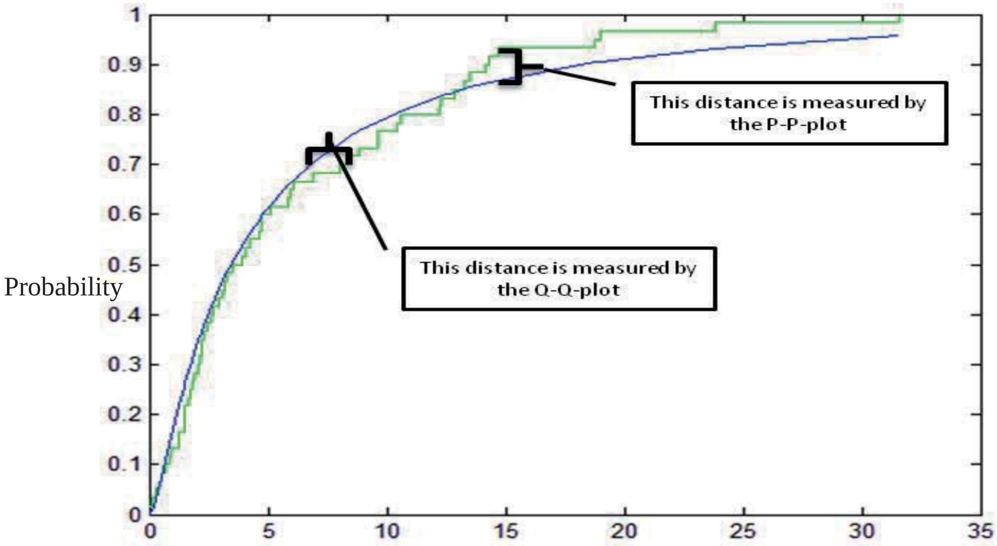


Figure 6. The stair function illustrates the empirical cdf and the smooth function the fitted cdf. This figure also illustrates what the Q-Q and P-P plot essentially measures.

A Q-Q plot is a plot of the cdf of the empirical distribution against the cdf of the fitted statistical distribution, which can be seen as y-values in *Figure 6*. The P-P plot on the other hand is a plot of the empirical pdf against the fitted statistical pdf, which can be seen as the x-values in *Figure 6*. The P-P plot for this figure can be seen in *Figure 7*. The Q-Q plot will look similar but will indicate on differences on the x-value in the plot as can be seen in *Figure 6*. To be a good fit the stars in *Figure 7* should follow the straight line, which indicates that the fitted distribution in *Figure 6* is not a good match. (Law and Kelton, 2000, p. 350-354)

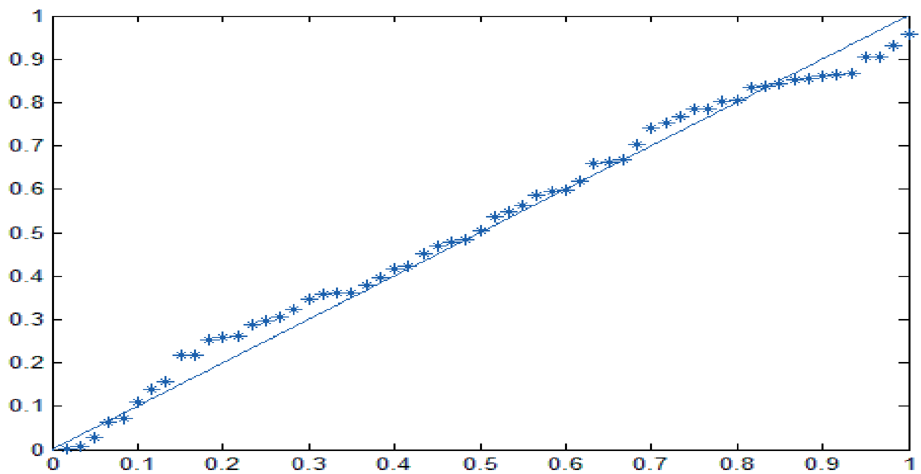


Figure 7. P-P plot for Figure 6.

4.4 Multi-echelon control of an inventory system – The MEM method

4.4.1 The customer demand

Since many items do not flow smoothly, fitting the demand process exactly can be complicated. A demand process can consist of smooth or lumpy demand, variations in demand over time and other unpredictable variations. Lumpy demand arrives in discrete, large lumps compared to smooth demand which arrives in a continuous stream. Generally, demand consists of a combination of both kinds. Seasonal variations over the year as well as unpredictable variations of the demand can also occur for some product categories. (Zipkin, 2000, p. 9-10)

When the demand at a retailer is high, an approximation where the demand initially is assumed to be normally distributed can often be used. For slow moving items with intermittent to lumpy demand a different distribution fit is more appropriate. For these articles the compound Poisson distribution is a better choice for modeling the demand. Berling and Marklund (2012; 2013) have developed a model for controlling a multi-echelon inventory system where the demand at each retailer is approximated to be either normally distributed or to follow a compound Poisson distribution. The disadvantage when using compound Poisson distribution can be that it is more computationally demanding and does not work for high demand items; hence, these items will be analyzed with a normal approximation. An important aspect of the model is that it allows for different demand distribution at different retailers. (Berling and Marklund, 2012). The model will be further explained in the in *Chapter 4.4.2*.

4.4.2 The MEM modeling approach

In the following section the MEM model developed by Berling and Marklund (2012; 2013) will be explained in detail. The model works in the same way for both compound Poisson demand and normally distributed demand since the assumption made on the demand at the retailer is the only difference. It does have significant on the analysis, though.

The MEM model assumes continuous review (R,Q)-policies at all locations. The model uses complete backordering at all stock points and the demand is served on a First-Come-First-Served basis. Complete backordering essentially means that all orders are backordered and the customers will wait as long as it takes to get the items they have ordered, i.e. no cancellation of orders. Demand is compound Poisson or normally distributed. The former is usually a good match for demand that is low and lumpy, while the normal approximation with the correct mean and variance during the lead-time is often a good fit for high demand items. For the normal approximation of the demand, the MEM model offers a method for adjusting the reorder points at the retailers for the occasion that some orders are triggered when the inventory position[7] is below the reorder point. This is referred to as an undershoot and it is caused by customers demanding more than a single unit. (Berling and Marklund, 2012)

There is an exact model by Axsäter (2000) which will determine the reorder points optimally assuming compound Poisson demand at all retailers. Because it is computationally demanding for larger systems it has limited practical applicability. Instead the MEM method developed by Berling and Marklund (2012; 2013) decomposes the two-echelon inventory system by the use of (what they call) an induced backorder cost. This induced backorder cost makes it possible to optimize each warehouse separately while still maintaining coordinated control, making it computationally fast and accurate.

The model by Berling and Marklund (2012; 2013) uses a coordinated approach to find new optimal reorder points in a two-echelon inventory system solving (14). The system consists of one central warehouse (CW) that replenishes its stock from an outside supplier with a constant lead-time (L_0). The system has N non-identical retailers which have a lead-time of L_i from the CW, consisting of a constant part l_i and a stochastic part. The constant part is the transportation time and the stochastic part is the possible delay that can occur if the CW has a stock-out. The batch size Q_i is given and is together with the inventory position and the reorder point an integer multiple of a sub-batch size Q.

[7] Inventory position = stock on hand + outstanding orders – backorders, where stock on hand considers how many items that can be found in stock, outstanding orders are the orders that have been placed but which have not yet arrived and backorders are demanded items that have not yet been delivered. (Axsäter 2006, p. 46)

Table 3. Parameters used for modelling and optimizing the multi-echelon inventory system. (Source: Berling and Marklund, 2012)

Parameter	Description
q_i	Batch quantity at retailer i, expressed in units of Q.
Q_i	Batch quantity at retailer i, expressed in number of units ($Q_i=q_iQ$).
Q_0	Central warehouse batch quantity, expressed in units of Q.
h_0	Holding cost[8] per unit and time unit at the central warehouse.
h_i	Holding cost per unit and time unit at retailer i.
p_i	Shortage cost[9] per unit and time unit at retailer i.
R_i	Reorder point for retailer i.
R_0	Reorder point at the central warehouse in units of Q.
L_0	Transportation lead-time from an outside supplier to the central warehouse.
l_i	Lead-time from the central warehouse to retailer i.
C_i	Expected inventory holding costs per time unit at retailer i.
C_0	Expected inventory holding costs per time unit at the central warehouse.
TC	Total system cost per time unit.
γ_i	Expected fill-rate at retailer i.
FR_i	Target fill-rate at retailer i.

[8] Holding cost – Consists of the opportunity cost for capital tied up in inventory. (Axsäter, 2006, p. 44) The holding cost used in this master thesis will also consist of all other costs connected to keeping inventory, such as risk for obsolescence, theft etc.

[9] Shortage cost – A cost incurred when a shortage of demanded items occurs which prevents the items to be delivered when expected. (Axsäter 2006, p. 45)

Minimization of the total costs in the multi-echelon inventory system is done according to expression (14) under the fill-rate constraints in (15). The relevant notations are explained in *Table 3 above*.

$$\text{Min } TC(R_0, R) = C_0(R_0) + \sum_{i=1}^{N} C_i(R_i, L_i(R_0)) \quad (14)$$

$$\text{Subject to } \gamma_i(R_i, L_i(R_0)) \ \geq \ FR_i \quad \forall\, i = 1,2, \ldots N \quad (15)$$

(Berling and Marklund, 2012; 2013)

Notations used to describe the model can be found in *Table 4*.

Table 4. Notations used in the models. (Source: Berling and Marklund, 2012)

Notation	Description
$\bar{L}_i$	Expected replenishment lead-time for retailer i
$D_i(t)$	Customer demand at retailer i during time t (stochastic variable)
λ_i	Customer arrival rate at retailer i
$f_i(j)$	Probability that a customer at retailer i demands j units
$f_i^k(j)$	Probability that k customers at retailer i demands a total of j units
m_i	Expected number of units demanded by a single customer at retailer i
v_i	Variance of the number of units demanded by a single customer at retailer i
$\delta_i(n)$	Probability that at most n batches of Q_i units (or q_i sub-batches) are triggered at retailer i during a time interval of length L_0
μ_i	Expected demand (in number of units) per time unit at retailer i
σ_i	Standard deviation of the demand per time unit at retailer i (in number of units)
μ_0	Expected lead-time demand (during L_0) in units of Q at the central warehouse
σ_0	Standard deviation of the lead-time demand in units of Q at the central warehouse
$D_0(t)$	Sub-batch demand (in units of Q) at the warehouse during t time units
IP_i	Local inventory position (=stock on hand + outstanding orders - backorders) at location i in steady state
IL_i	Inventory level (=stock on hand - backorders) at location i in steady state
$(x)^+$	Max(0,x), $(x)^-$ is defined analogously as max(0,−x)

The model uses a five step approach to find the near optimal reorder point for the inventory system:

1. Estimate a near optimal induced backorder cost at the central warehouse, β
2. Determine the lead-time demand at the central warehouse, $D_0(L_0)$, in units of Q
3. Determine a near optimal reorder point at the central warehouse, R_0*
4. Estimate the lead-time demand at each retailer i, $D_i(L_i)$.
5. Determine a near optimal reorder point at each retailer i, R_i*

Step 1: Estimate a near optimal induced backorder cost at the central warehouse, β

To determine the induced backorder cost (β_i) the model uses the method presented in Berling and Marklund (2006). The first step is to normalize the system parameters l_i, μ_i and h_i. In this model it means that a time unit is chosen so that $l_i = 1$, the unit of demand is chosen so that $\mu_i = 100$ and the monetary unit is chose so that $h_i = 1$. In *Appendix C* a conversion table showing how to move from the normalized system back to the original system is presented. As can be seen in *Appendix C* when the normalized $\beta_{i,n}$ has been calculated the β_i for the original system can be determined as $\beta_i = h_i * \beta_{i,n}$. The closed form estimate of β_i used by Berling and Marklund (2006) is (16).

$$\beta_i = h_i(g(Q_{i,n}, p_{i,n})\sigma_{i,n}^{k(Q_{i,n},p_{i,n})} \quad \text{For } i = 1,2 \ldots, N \tag{16}$$

To determine the two functions $g(Q_{i,n}, p_{i,n})$ and $k(Q_{i,n}, p_{i,n})$, see Table B1 and B2 or equations (13) and (14) in Berling and Marklund (2006).

When all the β_i, where i = 1,2,…,N, are determined β is estimated as the weighted average with respect to the expected demand per time unit, see equation (17).

$$\beta = \sum_{i=1}^{N} \frac{\mu_i L_0}{\mu_i Q} \beta_i \quad (17)$$

For further discussion and motivation of the estimation of β_i, see Berling and Marklund (2012; 2013).

Step 2: Determine the lead-time demand at the central warehouse, $D_0(L_0)$, in units of Q

Berling and Marklund (2013) propose an approach where the lead-time demand is approximated by fitting distributions to the correct mean and standard deviation. To do this first the subbatch demand from retailer i during L_0 time units are defined as $D_0^i(L_0)$ and its probability mass function $g_0^i(u)$ as (18).

$$g_0^i(u) = P\left(D_0^i(L_0) = u\right) = \begin{cases} \delta_i(0) & if\ u = 0 \\ \delta_i(n) - \delta_i(n-1) & if\ u = nq_i\ , n = 1,2\ ... \\ 0 & otherwise \end{cases} \quad (18)$$

The correct mean and standard deviation are calculated according to the formulas (19) and (20).

$$\mu_0 = (\mu_0^1 + \mu_0^2 + \cdots + \mu_0^N) \qquad where \quad \mu_0^i = (\mu_i L_0)/Q \quad (19)$$

$$\sigma_0^2 = (\sigma_0^1)^2 + (\sigma_0^2)^2 + \cdots + (\sigma_0^N)^2$$

$$where\ (\sigma_0^i)^2 = \sum_{u=0}^{\infty} \left(\mu_0^i - u\right)^2 g_0^i(u) \quad (20)$$

To increase the computational efficiency and accuracy three different distributions are used depending on the ratio between the mean, $\mu_{0,}$ and the variance, σ_0^2. The three distributions are as follows:

1. Negative Binomial distribution when $\frac{\sigma_0^2}{\mu_0} > 1$
2. Discrete Normal distribution $\frac{\sigma_0}{\mu_0} < 0.25$
3. Discrete Gamma distribution for all other cases

For further motivation of the distribution choices in the different intervals see Berling and Marklund (2013).

Step 3: Determine a near optimal reorder point at the central warehouse, R_0*

To find a near optimal reorder point at the central warehouse, the first step is to simplify the system described by (14) and (15) into (21), (22) and (23). This is possible since the model uses an induced backorder cost, see Berling and Marklund (2012) for details.

$B_0(R_0)$ in formula (21) is the number of backordered subbatches of Q at the central warehouse in steady state. This is true since the backorders at the central warehouse in steady state only depend on R_0 and not on the reorder points at the different retailers.

$$\mathrm{Min}_{R_0}\,\tilde{C}_0(R_0) = \mathrm{Min}_{R_0}\,\{C_0(R_0) + \beta Q E[B_0(R_0)]\} \tag{21}$$

$$\text{For } i = 1,2,\ldots,N \qquad \mathrm{Min}_{R_i} C_i(R_i, L_i(R_0)) \tag{22}$$

$$\text{Subject to } \gamma_i(R_i, L_i(R_0)) \geq FR_i \tag{23}$$

The expression for $\tilde{C}_0(R_0)$ when simplified is:

$$\tilde{C}_0(R_0) = \frac{(h_0+\beta)Q}{Q_0}\left\{\sum_{y=R_0+1}^{R_0+Q_0}\sum_{u=0}^{y}(y-u)g_0(u)\right\} - \beta Q(R_0 + \frac{Q_0+1}{2} - \mu_0$$

As β>0 it can be shown that $\tilde{C}_0(R_0)$ is convex in R_0^*, hence, a search where R_0 is incrementally increased can be used to find a near optimal reorder point for the central warehouse. The optimality condition is stated in formula (24) below.

$$R_0^* = \max\{R_0 : \tilde{C}_0(R_0) - \tilde{C}_0(R_0 - 1)\} \leq 0 \tag{24}$$

Step 4: Estimate the lead-time demand at each retailer i, $D_i(L_i)$

The focus in this step is to approximate the waiting time caused by stock-outs at the central warehouse, $W_i(R_0*)$, and thereafter the associated lead-time demand at retailer i, $D_i(L_i(R_0*))$.

The lead-time demand at retailer i, $D_i(L_i(R_0*))$, can be estimated through one of two methods, denoted M1 (the main approach) and M2. M1 is the one used in this thesis project, and hence, will be further described below.

M1 assumes that the replenishment lead-time to retailer i, $L_i(R_0*)$, is estimated by its mean, $\bar{L}_i(R_0*)$, i.e. a METRIC inspired approximation. The METRIC approximation was first published by Sherbrooke (1968) as a component of the METRIC model . For an identical set of retailers Little's law can be directly applied, see formula (25), to extract the correct mean of $L_i(R_0*)$. For non-identical retailers (25) instead gives an approximation of the correct mean.

$$\bar{L}_i(R_0^*) = l_i + \frac{L_0}{\mu_0} E[B_0(R_0^*) \qquad (25)$$

Berling and Marklund (2013) use formula (25) if partial deliveries are allowed at the central warehouse. A partial delivery is when the central warehouse is allowed to deliver for instance half the amount ordered to a retailer if it has a stock-out. This is true for the inventory system studied in this project.

Step 5: Determine a near optimal reorder point at each retailer i, R_i*

When the lead-time is estimated for each retailer, the multi-echelon system is decomposed and each retailer can be optimized using single-echelon methods. The objective function is to minimize $C_i(R_i)$ which expands into (26).

$$\text{Min } C_i(R_i) = \text{Min}_{R_i} h_i E[(IL_i)^+] + p_i E[(IL_i)^-] = -p_i E\big[(IL_i) + (h_i + p_i) E[(IL_i)^+]\big] =$$

$$-p_i \left(R_i + \frac{Q_i+1}{2} - \mu_i L_i\right) + (h_i + p_i) \sum_{j=1}^{R_i+Q_i} j P(IL_i = j \mid R_i) \qquad (26)$$

Let us define the ready rate = $P(IL_i > 0|R_i)$. This gives formula (27).

$$\Delta C_i(R_i) = C_i(R_i + 1) - C_i(R_i) = p_i + (h_i + p_i) P(IL_i > j|R_i + 1) \qquad (27)$$

The ready rate is increasing in R_i, hence $\Delta C_i(R_i)$ is increasing in R_i. This implies that $C_i(R_i)$ is convex in R_i, and the optimal condition for R_i can be obtained as (28).

$$P(IL_i > 0|R_i^*) \leq \frac{p_i}{h_i + p_i} < P(IL_i > 0|R_i^* + 1) \quad (28)$$

Another interesting thing to notice is that $P(IL_i > 0|R_i) = 0$ for $R_i = -Q_i$ which means that when optimizing R_i the search can be started at $-Q_i$.

The implicit assumption with the standard approach of optimizing R_i during the normal approximation method is that the replenishment order is always triggered when the reorder point is reached. However, this assumption will not hold if the quantities for a customer demand is larger than 1. Instead a replenishment order will be placed when the inventory position is below the reorder point. This phenomenon is by Berling and Marklund (2012) called undershoot. In their model they use two different approaches to compensate for this undershoot and adjust the reorder points accordingly. For an explanation of these adjustment methods see Berling and Marklund (2012). The undershoot can significantly lower the fill-rate, and hence, compensating for it is of major importance for the normal approximation model to fulfill the fill-rate constraint. Consequently, the undershoot is a very important component of the Berling and Marklund model for the normal demand at the retailers. However, all the demand data studied at the case company was modeled according to a compound Poisson process and therefore this matter are not discussed further. For a deeper discussion and explanation of the matter see Berling & Marklund (2012).

4.5. Environmental Impact

The global warming as a result of greenhouse gases produced by humans was first observed in the middle of the 20th century. The average temperature near the earth's surface has increased between 0.18 and 0.74^{o}C during the last 100 years. The greenhouse effect[10] will, according to scientists lead to a change of climate all over the world. Different areas will get different changes; some of the changes mentioned by scientist are increased dryness, increased rainfall and flooding, increased forest fires,

[10] Increase of earth temperature due to greenhouse gases

higher sea water levels and major effects on agriculture and ecosystems. All these extreme changes are not free of charge and will according to economic experts lead to higher costs for the society. They have estimated the economic losses to be somewhere between $3-95 per tonnage carbon dioxide (CO_2). (Samimi and Zarinabadi, 2011)

4.5.1 Metric of environmental impact

There are mainly four types of greenhouse gases (GHG); CO_2, CH_4, N_2O and F-gases whereas transportation accounts for 19.7% of the total emissions in the EU-27 (European Environment Agency, 2012). One of the most used metrics of environmental impact is the Carbon Footprint (Hauschild et. Al, 2012). CO_2 is also the largest contributor to the greenhouse gases (European Environment Agency, 2012) which is used as a metric by the UN in the Kyoto protocol (Nationalencyklopedin, 2013a).

Because of its wide acceptance CO_2-equivalents is the metric which will be used in this report to measure the environmental impact of a particular mode of transportation. This is also the metric used by Lantmännen (Hersner, 2013a).

4.5.2 Greenhouse gases and the transportation business

Greenhouse gas emissions differ widely depending on the type of transportation mode used. Air transportation is by far the worst polluter when it comes to greenhouse gases and maritime shipping is the most environmentally friendly mode. In *Table 5* average emissions of CO_2 per tonne-km can be viewed. (Cristea et. al., 2013)

Table 5. Emissions of CO_2 in gram per tonne-km and transportation mode. (Source: Cristea et. al., 2013)

Mode of transportation	CO_2 per tonne-km (g)
Maritime	
Bulk	4.5
Container	12.1
Land	
Road	119.7
Rail	22.7
Air	
US Cargo fleet	912-963.45

4.5.3 Method for calculating CO_2-emissions

The Network for Transport and Environment (NTM) is a non-profit organization which has developed a method for calculating emissions of Green House Gases (GHG) which can be found at http://www.ntmcalc.org/index.html. This method will be used in this thesis to compare different modes of transportation with respect to CO_2-emissions, i.e. environmental impact. The methodology used by NTM will be described in the following paragraphs.

This master thesis focuses on the reduction of emergency orders that can be achieved by a better control of the inventory system, and by that also a reduction of the CO_2-emissions. The emergency orders studied at the case company are either transported by air to the north of Sweden or by truck to the south and middle of Sweden. Consequently, only the methods proposed by NTM which contemplates these two modes will be investigated and described here.

Land transport

NTM describes the calculation of environmental impact as a process with 8 steps, see *Figure 8.*

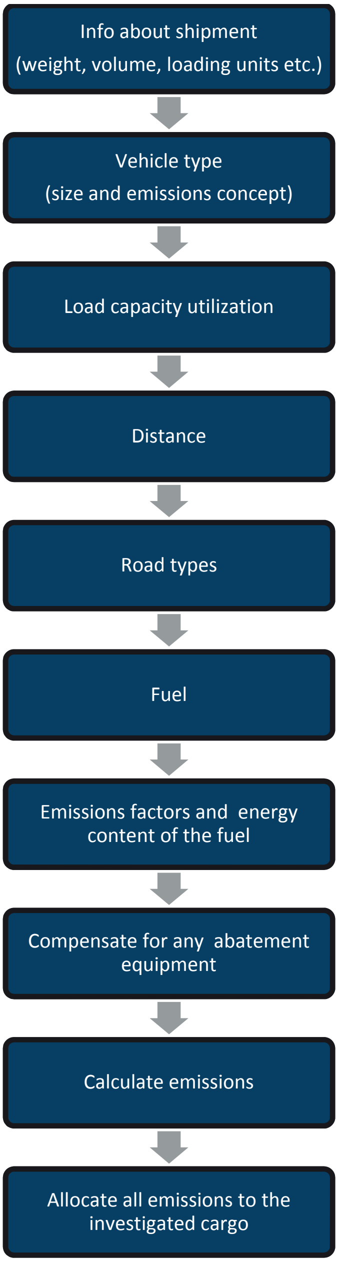


Figure 8. NTM's process for calculating environmental impact of land transport (Source: NTM, 2010)

The first step in the calculation is to gather information on what type of shipment that is sent, essentially the weight and volume of it. The next step is to find out which type of vehicle that is used and what load capacity and load utilization it has. Larger vehicles increase their environmental efficiency quite much when the load factor goes up. The next bit of information needed is the distance and road type. Evidentially, the distance plays a big role but also the road type will make a difference in the calculations. Preferably, information is gathered on a distance per road type basis. The next component is the fuel; this will make a difference since different types of fuel consists of different amounts of carbon, sulfur and aromatic hydrocarbons. NTM has gathered average values for fuel consumption in the unit [l/km] for full and empty vehicles on urban roads but they encourage the user to try to obtain data on their specific transportation to increase the accuracy of the calculations. When the fuel consumption is decided upon, the next step is to set the emissions factors for the fuel and the energy content since this will be needed to calculate the emission and energy consumption of the transport. The calculated values will then be compensated for exhaust abatement techniques which will reduce some emissions through catalyst and filters used in the vehicle. (NTM, 2010)

Calculations of environmental impact per item sent with land transport in this master thesis

This master thesis follows the process used by NTM in *Figure 8* to calculate the environmental impact per item transported between the central warehouse and each retailer where the item have been sold according to the gathered data. The procedure follows the steps below:

1. Gather data on the weight per item
2. Decide upon vehicle type
3. Decide upon fuel
4. Average load capacity used in Sweden
5. Road types, use average
6. Fuel
7. Calculation of emission

(NTM, 2010)

The calculations of the emissions are performed in two steps, first the fuel consumption is calculated and then the emissions from this consumption are determined. The fuel consumption per item depends on the loading capacity of the vehicle. If the loading capacity is high which they are for a regular replenishment order, the fuel consumption per item is low. For an emergency order the loading capacity can be anticipated to be lower than for a regular transport and hence the CO_2-emissions per transported kilo can be assumed to be higher. The only way to find out the loading capacity of emergency transports are to ask the transporting company performing these type of services. (NTM, 2010)

Expression (29) is used by NTM to calculate fuel consumption based on loading capacity. It needs as input the fuel consumption at 0% and 100% load utilization.

$$FC_{LCU} = FC_{empty} + \left(FC_{full} - FC_{empty}\right) * LCU_{weight(phys)} \quad (29)$$

$$LCU_{weight(phys)} = Load\ Capacity\ Utilization, defined\ as\ [cargo\ physical\ weight / \max weight\ capacity]$$

$$FC_{LCU} = Fuel\ consumption\ at\ load\ capacity\ utilisation\ LCU$$

(NTM, 2010)

When the fuel consumption for the chosen load utilization has been calculated, the emission which can be derived from the specific item is calculated. If it is a regular freight transport, the fuel consumption for this item and transport is calculated according to the formula (30).

$$FC_{Item} = \frac{Weight_{Item}}{LCU * Total\ capacity} * FC_{LCU} \quad (30)$$

(NTM, 2010)

After this, the final calculation is to multiply the fuel consumption for the item with the distance and the emissions per liter.

Air transport

Three different types of aircrafts can be specified for transport: pure passenger, combined passenger and freight and pure cargo freighters. The major benefit of air transport is its possibility to fast reach most parts of the world, while an environmental drawback is the high GHG emissions compared to road transport. (NTM, 2011)

The emissions calculations for air transport depend on the type of aircraft chosen since the emissions vary with engine configuration and type, e.g. less volume and weight of a passenger aircraft is used by the freight, and hence less emissions is dedicated to the freight compared to a freight air craft. (NTM, 2011)

To calculate the emission of an individual shipment sent by air transport the total emission first has to be calculated. Secondly, the weight of the individual unit including secondary packaging compared to the total weight of all cargo is used to allocate emission to this shipment unit. Information about flight distance, aircraft model, load factor and weight of the unit to send is required to perform the emission calculation. The total emission (TE) can be obtained through formula (31) below. The description of the parameters in formula (31) can be found in *Table 6*. The emission factors in the NTM database are divided into Constant Emission Factors (CEF) and Variable Emission Factors (VEF), where the first one is affected by the high fuel usage during takeoff and landing and the latter one is multiplied with the (great circle) distance in km. (NTM, 2011)

$$TE_i = CEF_{(i,cu)}[kg] + VEF_{(i,cu)}[{}^{kg}/_{km}] \times D[km] \qquad (31)$$

Table 6. Description of parameters used in formula (31). (source: NTM, 2011)

Parameter	Description
$\mathbf{TE_i}$	Total Emission of substance (i)
$\mathbf{CEF_{(i,cu)}}$	Constant Emission Factor for substance (i) at capacity utilization (cu)
$\mathbf{VEF_{(i,cu)}}$	Variable Emission Factor for substance (i) at capacity utilization (cu)
D	Great Circle Distance between airports (GCD)

The values of CEF and VEF for various aircrafts and different greenhouse gases (CO_2), and load factors are available in NTM's database. The trip distance (D) is calculated as the Great Circle Distance, GCD, between two locations and is defined as the shortest distance between two points on the surface of a sphere, see formula (32). The geographical coordinates for these points can be used to calculate the distance.

$$D = Rcos^{-1}[(\sin(lat1)\sin(lat2) + \cos(lat1)\cos(lat2)\cos(lon1 - lon2)] \qquad (32)$$

The coordinates for the two points corresponds to {lat1, lon1} and {lat2, lon2} and R=6371.01 km is the mean radius of the earth. (NTM, 2011)

The fuel consumption, FC, can be obtained through formula (33):

$$FC[kg] = CO_2 \frac{[kg]}{fuel\ specific\ CO_2} \qquad (33)$$

In this formula, the fuel specific CO_2 can be found in NTM's fuel specification tables. (NTM, 2011)

The total emission need to be allocated also for the shipping unit. For air transport the weight is a delimiting factor that can be essential to use when defining total environmental performance, and hence, it should be the basis when allocating the environmental burden. The weight used for the calculation should include, for example, the weight of containers, cargo handling and security devices. (NTM, 2011)

The weight of the passengers for a certain flight can be derived by either setting an average weight of about 100 kg per passenger including the weight of luggage or by using individual weights for males, females and children, depending on type of flight and destination. The latter option usually leads to a somewhat lower passenger loads. (NTM, 2011)

Recommended by NTM, the total allocation should be based on mass weight of cargo and passengers where the overall mass consists of payload and the mass of specific equipments essential for the transportation. Since the structure of the airplane and the weight of the flight crew and the cockpit equipment are required for the transportation they are not accounted for. The weight of the other equipment, freight and passengers are instead summed up to be able to split up the emissions on respective weight. (NTM, 2011)

5. Data Analysis

This chapter will describe the analysis conducted on the data used for the Excel model and the simulations. The data from Lantmännen was extracted from Syncron's database according to the delimitations set in this project. Furthermore, a sample of 106 representative items was selected through stratified sampling of the entire population of 9659 items. Subsequently, distribution fitting was done for these articles to find suitable distributions for each item. The relevant data about CO_2-emissions was gathered from the transportation companies contracted by Lantmännen and from the database of NTM.

5.1 Delimitations in the data extraction

To be able to find appropriate distributions for describing the input data to the models, historical transaction data from Lantmännen was extracted from the ERP system. In consensus with the other parties involved in this project some constraints were set to the data material to exclude certain items, retailers and suppliers. These restrictions are as follows:

- **Only the demand during the time period January 2011 to December 2012 is studied**
  - Only transactions made during this time period were extracted. To include variations of the demand during a year, such as seasonality, the time period was set to be at least one year. Since many spare parts are demanded at a very low frequency, the transactions for a time span of two years were decided to comprise a wider range of articles in the initial analysis. This time span was discussed with Lantmännen and Syncron and two years were agreed to be an adequate time period to study.

- **Only retailers on the Swedish market are considered**
  - Transactions outside the Swedish market, i.e. Norway and Denmark, were excluded since most facilities there are owned by external parties outside Lantmännen which do not use the same ERP system.

- **Only articles demanded at least once during the time period of January 2011 to December 2012 are studied**
  - Articles not demanded during this time period could not be included in the analysis since it was not possible to perform any calculations on these items.
- **Only articles which Lantmännen have decided to keep in stock at their retailers are studied**
  - Only articles kept in stock were analyzed since the non-stocked items did not follow the ordinary inventory policy. As a consequence, articles with a price over 10 000 SEK were not included since Lantmännen generally do not stock these items because of the high holding costs.

In addition to these general specifications the following restrictions were imposed when extracting the data:

- **Facilities in Sweden owned by external parties are not studied**
  - Data for Kalmar Lantmän is excluded since this facility is owned by an external party, and hence, might not follow same restrictions and inventory policies as the internal retailers do.
- **Common goods in the store are excluded**
  - These items were excluded since they do not follow the normal flow of goods nor the normal stocking policy. This is because some products are only kept in the shops to keep the shelves full rather than actually being demanded. Subsequently, the suppliers only delivering shop items were left out from the data.
- **Suppliers delivering straight to the retailers without passing the central warehouse are excluded**
  - The articles from these suppliers were removed from the data because their physical flow did not go through the central warehouse, and subsequently, fall outside of the scope of this study.

With reference to theses delimitations and reductions in the data material, data was extracted in three different files with the characteristics described in *Appendix A.* These extractions contained useful information about:

- Date and size of all demands occurring at the retailers and at the central warehouse per item.
- Planned lead-times between the central warehouse and the retailers, and the outside supplier and the central warehouse. These lead-times are defined as the time from an order is sent from the retailer to the central warehouse until the delivery of the requested item arrives at the retailer. The same definition applies for the flow between the outside supplier and the central warehouse. Important to clarify is that these lead-times are the planned lead-times thus they assume that there is no delay because of stock-outs or other capacity restrictions at the central warehouse or the outside supplier.
- Item information such as weight per unit and cost per unit.
- Current stock.

When all constraints where considered the final data extracted from the Syncron system consisted of 9 745 items. Furthermore, these where scaled down to a final test sample of 106 items through stratified selection. How this was done is explained in *Chapter 5.2*.

5.2 Stratified selection

To reach a more manageable data size for the analysis, a stratified selection was performed on the entire data sample extracted from the system. Obviously, the most accurate results would be achieved if all items were studied. Due to time limitations in these kinds of thesis projects this is often not possible. In addition, the approach is also somewhat unpractical. Instead the sample size has to be small enough to fit into the time-frame of a thesis project but also large enough to make the results reliable. These two aspects were considered simultaneously when deciding a test sample size for the simulations in Extend. Concerning these limitations a test sample of about 100 articles were seen as a feasible amount to analyze.

5.2.1 Strata characteristics

The whole population of articles in the extracted data material was divided into strata characterized by the following criteria:

- $\frac{\sigma}{\mu}$, standard deviation divided by the mean
- Mean of demand
- Cost of product
- Emergency transports by air or not
- Weight

These criteria were set to give a wide spread of articles included in the final test sample. The advantage of creating strata with these characteristics was that it made it possible to ensure that important aspects affecting the inventory system and analysis was considered. Due to this selection it could be assured that e.g. different types of transportation modes would occur in the test sample. In *Table 7* a summary of the characteristics of the strata can be found together with the intervals they were divided in. The upper limit of the intervals is set as the largest value occurring in the sample data for this parameter, while the other boundaries are described in the paragraphs further down.

Table 7. Characteristics of the strata in the stratified selection.

Criterion	Number of sub-groups	Intervals
$\frac{\sigma}{\mu}$ per month	2	0<=x<1 & 1<=x<5
Mean demand per month	2	0<=x<5 & 5<=x<20 000
Cost of product (SEK)	3	0<=x<100, 100<=x<500 & 500<=x<10 000
Emergency transport by air	2	Yes & no
Weight (kg)	2	0<=x<25 & 25<=x<250
Total	48	

The mean and standard deviation used for the stratified selection was calculated per month. The decision to choose month instead of days was made because then 24 values per item were needed instead of 730 values per item. Since Lantmännen has 9 745 items the extra accuracy did not compensate for the extra calculation time needed.

$\frac{\sigma}{\mu}$ was selected as a criterion since the analytical multi-echelon model, MEM, implemented in Excel, and the distribution fitting would be affected by this value. By setting the boundary between the intervals to 1 it was possible to ensure that both articles with low standard deviation compared to the mean and those with high would be included in the test sample.

The distribution fitting is dependent on the type and size of demand, and thereby, the articles were sorted according to the mean demand to obtain a wide range. Incorporating different types of mean demand makes sure that this important parameter is representative in the sample.

A purpose of this project is to identify possible environmental benefits of using the MEM model. The hypothesis was that the number of emergency transports by air is the factor affecting the environmental impact of the inventory system the most. Because of this hypothesis the strata where also sorted according to mode of emergency transport. In the inventory system all emergency transports to retailer locations north of Uppsala, Örebro and Karlstad and also two locations in the east; Visby and Hemse in Sweden are sent by air. Hence, it was significant to include items sent to these locations. For air transports there is a weight limit of 50 kg which result in heavier articles being transported to the north and east by truck even when it comes to emergency orders. (Hersner, 2013a) These articles ended up in strata with the characteristic “no flight” even though they are sent to the north or east.

The cost criterion ensured that the test sample included expensive as well as cheap products, since it has an impact on the cost of the inventory system in different ways. For instance, the most evident one is the higher holding cost for an expensive item. This aspect is important when it comes to investigating the cost benefits of multi-echelon inventory control which is also part of the purpose of this master thesis.

To cover a broad range of article weights, the weight criterion was set to include both heavy and light products. However, since most articles had a weight below 10 kg, there were just some few selected from the strata with the weight interval above 25 kg.

5.2.2 Selection of test sample

When the characteristics of the strata were selected, the entire extracted data sample were divided into 48 different strata according to the characteristics, see *Appendix D*. To generate a sample of about 100 representative articles to analyze further, a number of articles were then randomly picked from each stratum in proportion to the stratum’s fraction of the entire extracted data sample. Some small strata did not have enough items compared to the entire sample to attain 1 % of the test sample. To still include articles from these small strata one item from each one where randomly selected in excess of the 100 articles. From the strata which contained enough items, articles where randomly picked analogously to the percentage the strata covered. After this stratified selection a test sample of 106 items were obtained, which can be found in *Appendix E*.

5.2.3 Selection of retailers for each item in the test sample

The simulation model, explained in C*hapter 6*, was built to suit input parameters for a maximum of 10 retailers for a specific item. Since a majority of the items at Lantmännen (about 60%) was only demanded at 1-10 retailers (at most there are 53 retailers demanding the same article) a decision was made to limit the considered system to at most 10 retailers per item. The motivation is that the focus in this project is on comparing the benefits that can be achieved by multi-echelon control and not to rebuild and test the available model more than necessary. Even though the validity of the results would have increased by adding 43 retailers, the internal validity of the simulation model would not. The reasoning behind this is that the simulation model has been validated and used with 10 retailers for several earlier research projects. By adding more retailers the whole structure of the model would have needed to be redone. Such a significant change would essentially mean that the model could not be seen as the old verified model but instead as a new non-verified model.

For the items which were demanded at more than 10 retailers during 2011 and 2012 (40% of the items), 10 retailers were randomly picked. This reduction was performed through a random selection of retailers for each item with originally more than 10 retailers. After the reduction of the number of retailers was made the test sample was compared to the whole original data sample to make sure that the relative amount of retailers using air transport for emergency orders was the same as before the reduction.

5.3 Distribution fitting

The next step in the data analysis was to determine distributions for the end demand of each item. This was done by fitting a normal distribution if the coefficient of variation, $\frac{\sigma^2}{\mu}$, was below 1, a Poisson distribution if it was equal to 1 and a compounding distribution if the coefficient of variation was larger than 1. Depending on the characteristics of the demand data a suitable distribution can be determined by performing statistical analysis in the StatFit module in Extend. As an attempt to sort out items suitable for the StatFit analysis, a careful investigation of all the items in the final test sample was performed. Particularly, the frequency, size of demand, and alignment between different retailer locations were checked to select those items applicable for StatFit testing. It turned out that most items had very low-frequent demand, sometimes only demanded once or twice per two year at a retailer of a certain article. When there are very few observations in the data sample, fitting a distribution gets a bit problematic. The chi-squared test needs at least 30 observations to be adequate to use. Even though the Kolmogorov-simonov test works for fewer observations it is only applicable for the Normal, Exponential and Weibull distributions. Further, Statfit requires at least 10 values of diverse size to be able to search for a fitting distribution. Since Statfit is the program chosen for the distribution fitting and few observation lead to uncertain estimations of the distribution, a number of 10 observations was set as the limit for when to perform distribution fitting.

All the retailer demands studied had a coefficient of variation equal to 1 or above 1. For the demands which had a coefficient of variation equal to 1 the Poisson distribution was chosen. For the rest of the demands a compound Poisson distribution was chosen. After analyzing the data it turned out that only three items had at least 10 observations at any retailer. A distribution fitting was performed in Statfit on the retailer demands that fulfilled the criteria to see what type of compounding distribution would fit. The fitted distributions from the StatFit runs for these items varied between geometric, logarithmic and negative binomial distribution, and can be found in *Table 8*. No item had a perfect fit for the demand at all retailers. Since the current implementation of the MEM model in Excel requires the same settings for all retailers of an item, it was concluded to use empirical compound Poisson distribution for item 24, 70 and 71 as well.

The empirical compounding distribution consists of a lambda which is fitted to the mean and the probabilities that different demand quantities occur at that retailer. From this fitted lambda, the standard deviation was calculated and compared to the standard deviation of the historical data. This test showed that the largest deviation from the fitted standard deviation was 4% for any retailer but most of the deviations were below 0.5%. This test indicates that the compound Poisson process offers a reasonable approach for modeling the demand at the retailers.

Subsequently, when all items, retailers and required input parameters for the analysis were obtained the Excel analysis explained in *Appendix G* could be initiated.

Table 8. Results from the StatFit runs for item 24, 70 and 71 for the compounding distribution.

Item	Retailer	Distribution
24	280	Sample too small
24	350	Geometric, Logarithmic
24	430	Sample too small
24	530	Sample too small
24	670	Geometric, Logarithmic
24	790	Sample too small
24	800	Sample too small
24	850	Negative binomial, Geometric, Logarithmic
24	880	Negative binomial, Geometric, Logarithmic
24	890	Geometric ,Logarithmic
70	170	Sample too small
70	180	Sample too small
70	280	Sample too small
70	300	Geometric, Logarithmic
70	350	Negative Binomial
70	410	Sample too small
70	540	Sample too small
70	650	Sample too small
70	760	Sample too small
70	890	Sample too small
71	160	Sample too small
71	430	Logarithmic, Geometric
71	540	Sample too small
71	580	Negative Binomial, Geometric
71	630	No fit
71	640	Sample too small
71	650	Sample too small
71	670	Negative Binomial, Geometric ,Logarithmic
71	730	Sample too small
71	780	Sample too small

5.4 CO_2-emission

To be able to compare the differences in CO_2-emissions between the SCP model and the MEM model, the CO_2-emissions caused by transportation were calculated for the two systems. In the multi-echelon inventory system of Lantmännen road transport is used for all replenishment orders. For the emergency orders, however, the transportation mode differs between land and air. This is because an emergency order needs to be delivered early the next day to the retailer and for some geographical locations it is impossible to do this by land transport. (Hersner, 2013a) The different regions which are served by air or land transport for the emergency orders are illustrated by the map in *Figure 9.* All emergency transports up to the three markers with a dot in the middle in *Figure 9*, which are the cities Karlstad, Örebro and Uppsala, are performed by land transport and the rest by air transport. Apart from this, emergency orders to the island of Gotland are also transported by air. Gotland is the island marked with a marker with an A in the middle in *Figure 9*.

To estimate the CO_2-emission from emergency shipments in the inventory system the average emissions per kg and type of transport were calculated using numbers from the organization NTM (Network for Transport and Environment) and the transportation companies HIT and Jetpak. Since the emissions vary between road transport for emergency orders and normal replenishment orders due to lower capacity utilization in emergency trucks, both values were determined. The total CO_2-emission for all the test items and the locations they are sent to can be found in *Appendix I*. The CO_2-emission calculations for road transport, and air transport, respectively, are explained in *Chapter 5.4.1* and *5.4.2*.

Figure 9. Map showing the geographical areas where different types of transportation modes are used for emergency orders.

5.4.1 Road transport (Distance and chosen vehicles)

All replenishment orders and the emergency orders to locations south of and including the regions of Karlstad, Örebro and Uppsala are transported on road. Depending on the type of truck and the capacity utilization of the truck transporting these orders, the CO_2-emissions differ between normal and emergency orders. How the emissions were calculated for each type of order is explained in the following sections.

Regular replenishment orders

The regular replenishment orders for Lantmännen Maskin AB are transported with the logistics provider HIT. HIT uses terminals to increase the load factor of their transports. To calculate the distances between the central warehouse and the different retailers as accurately as possible the actual location of each of HIT's terminals was obtained. (Hersner, 2013b) NTM proposes the following methodology to calculate the distance and which vehicle type to choose:

1. Determine the distance between the two major cities (or terminals) where the goods are transported. Assume that they are transported between these two cities on a truck and trailer, for Sweden and Finland and otherwise a semi-trailer. Use the default capacity utilization for this vehicle type, which is 60%.
2. To calculate emissions from the pick-up and delivery, assume that a medium truck is used and calculate the distance from the city of origin to the nearest major city (terminal) and then vice versa for the delivery city. Use the default capacity utilization for this vehicle type, which is 50%.

(NTM,2010)

Google Maps Distance Matrix[11] has been used to calculate the distance between the different cities. The calculations for CO_2 has been carried out

[11] https://developers.google.com/maps/documentation/distancematrix

in same steps as described by NTM, see *Appendix H*. Primarily, it consists of two different calculations, one for the transportation between the two terminals and one for the pick-up and delivery. For both calculations Euro Diesel class IV has been used since this is the type NTM uses in their examples of their method. The load utilization of 50% for pick-up/delivery and 60% for transport between terminals has been used, since the actual load utilization is unknown and under such circumstances these are the load utilization proposed by NTM. The distribution of different roads used for the actual transports is unknown. The distribution used is based on statistics for the total transportation work in Sweden and is used by NTM. This is motorway 94%, rural roads 4% and urban roads 1%. The motivation for using these values is that NTM uses them in a calculation example for the route between Gothenburg to Kiruna. (NTM, 2010)

Emergency transports

Average values of the CO_2-emissions for emergency transports by road were received from HIT, since they handle these kinds of shipments with their service *HIT InNight.* These values show the emissions per kg goods sent in Sweden independently of the distance the goods travel.

5.4.2 Air transport (Distance and chosen vehicles)

Concerning air transport at Lantmännen Maskin, only emergency orders are sent by this mode. By using emission data from the transportation company Jetpak, which handle emergency orders to the regions requiring air transport, the CO_2-emission per kg goods sent could be estimated. In *Table 9* a summary of the CO_2-emission released, according to Jetpak, can be found.

Table 9. CO_2-emission [kg CO2/kg goods sent] for air transport according to Jetpak. (Source: Jetpak, 2013)

From City	To City	CO2 (kg) per kg
Malmö	Skellefteå	0.2939
Malmö	Visby	0.2530
Malmö	Luleå	0.3681
Malmö	Umeå	0.2500
Malmö	Östersund	0.4808

Since the CO_2-parameters from Jetpak appeared uncertain, they were compared to numbers obtained from Posten (2013b) in a sensitivity analysis, shown in *Chapter 8.3*. At Posten 0.92 [kg CO_2/kg goods sent] is used as an average to any destination in Sweden. If only the air transport between Malmö and Umeå is accounted for Posten uses the value 1.5 [kg CO_2/kg goods sent], which is used as the maximum emission for air transport in the sensitivity analysis. The method from NTM, explained in *Chapter 4.5.3*, was also used to check if the emission data from the transportation companies seemed reasonable. The values obtained from the NTM calculations can be seen in *Table 10* below. The NTM method was used to estimate the emissions from air transport between Malmö and Skellefteå, since Skellefteå is the location with most observations in the data in terms of emergency transports by air. The NTM calculations gave an average of 1.86 [kg CO_2/kg goods sent]. To arrive at this, the emission from air transport between Malmö and Stockholm was added to the emission from air transport between Stockholm and Skellefteå. This is because the air transport within Sweden goes through Stockholm. Since Skellefteå is located further away from Malmö than Umeå is, the estimate obtained from NTM was considered well in line with the 1.5 [kg CO_2/kg goods sent] obtained from Posten.

Table 10. CO2-emission [kg CO2/kg goods sent] for air transport between Malmö (MMX) and Skellefteå (SFT) via Stockholm (ARN) according to NTM (2011).

Load factor[12] Cargo/Cabin	MMX-ARN	ARN-SFT	Total
100%/90%	1.05	1.11	2.16
50%/90%	0.62	0.58	1.21
100%/65%	1.30	1.22	2.52
50%/65%	0.81	0.75	1.56
Average	0.95	0.91	1.86

Since the numbers from Jetpak were the lowest they were used in the assessment of the total CO_2-emission from air transports in the inventory system. The reason for this was to ensure that the results would not be

[12] The load factor shows how well the cargo space respectively the cabin space is utilized.

exaggerated. The figures used were 0.25 [kg CO_2/kg goods sent] for Visby and 0.3 [kg CO_2/kg goods sent] for the rest of the airports in Sweden.

To decide which airport the goods from Malmö was flown to for each retailer a list of all airports in Sweden was used. The assumption was then made that the goods are flown to the airport which is closest to the retailer needing the emergency goods. To be on the safe side every airport was checked so that Jetpak had an office there.

In the calculations concerning the CO_2-emissions for emergency transports by air it is assumed that an ordinary distribution truck with normal loading utilization, 50%, is used (NTM, 2010). This approximation was done since the actual transportation between the central warehouse and the airport and then from the airport to the retailer is not known in detail. The mode of transportation also varies for these transports, which was another reason for using this approximation. The actual transportation between the central warehouse and the airport and from the airport to the retailer is, however, performed by Lantmännen themselves. As a comparison the distance between Malmö and the closest airport is 60 km back and forth. A Volkswagen Transporter 2.0 Turbo Diesel emits 0.2 kg per km of CO_2, which sums up to 12 kg CO_2 for a transport from the central warehouse to the airport. In comparison the transportation by air emits 0.3 kg CO_2 per transported kg. (Volkwagen Transportbilar, 2013)

6. Simulation Model

This chapter will describe the design of the original simulation model in Extend and the different blocks and assumptions it is built upon. Further, the changes made to the model to incorporate emergency orders are explained followed by some tests done to validate the reconstructed model.

6.1 Current Simulation model

To model the existing inventory system, a simulation model developed at the division of Production Management at Lund University was used. From now on this model is referred to as the *basic model*. This model represents a multi-echelon inventory system with (R,Q)-policies at all inventory locations and compound Poisson demand at each retailer. Since the basic model could not handle emergency orders it was customized to incorporate this feature. A conceptual picture of the simulation model can be seen in *Figure 10*. The demand is modeled by the block *compound Poisson*, each retailer by two blocks *Retailer Trigg* and *Retailer Inventory, and* the central warehouse is modeled by the block *Central Warehouse* and the delivery by the block *Complete Delivery*. In *Appendix F* a picture of the simulation model in Extend in entirety can be seen.

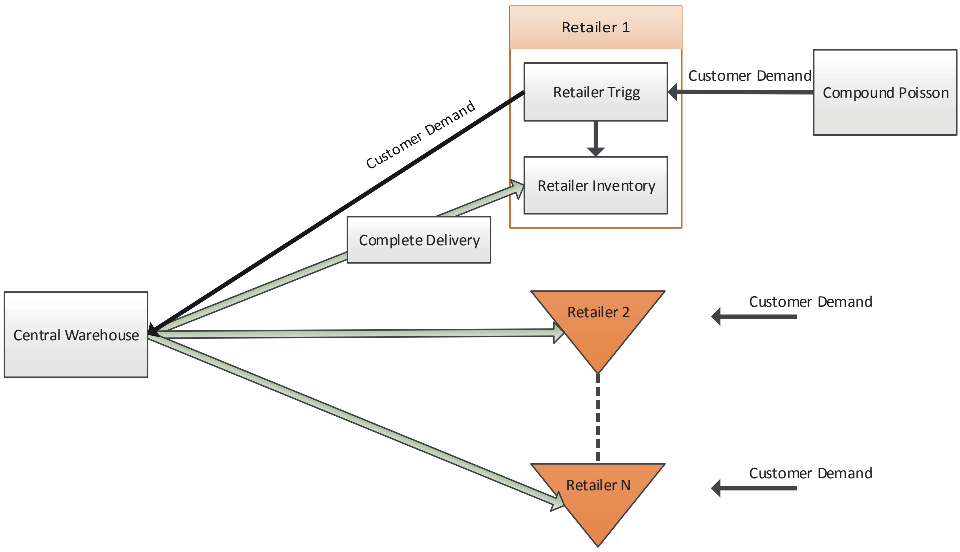


Figure 10. Conceptual picture of the simulation model. The black arrow equals the demand flow from customers to retailers and from retailers to the central warehouse. The gray arrows equals flows of items from the central warehouse to the retailers according to orders and the black dotted line shows that there are up to N number of retailers in the inventory system.

As the name indicates the block *compound Poisson* models a demand where the times between arrivals are exponentially distributed and the quantity demanded by each customer has a given distribution specified in the software. This block can be seen in *Figure 11*, where block A generates customers with time between arrivals according to the exponential distribution. The demanded quantity is generated in block B and block C sets the quantity given from Block B to each customer passing through. The customer is now ready to move to the block *Retailer Trigg*.

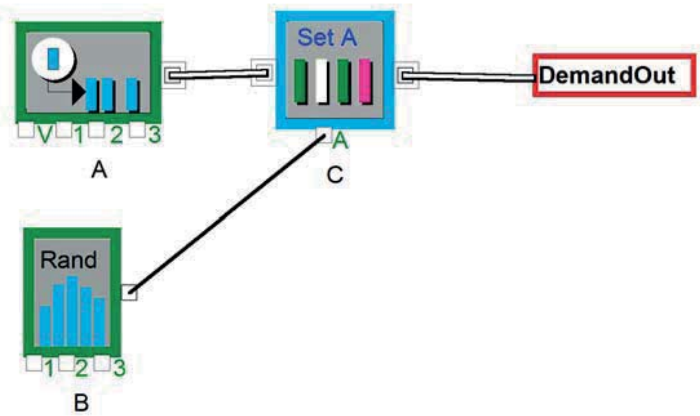


Figure 11. Simulation block compound Poisson.

The sole purpose of the *Retailer Trigg* block is to model the batch ordering process at each retailer and pass this batched demand to the central warehouse when the reorder point at the retailer has been reached. A picture of *Retailer Trigg* can be found in *Figure 12*. The flow starts at "demand in" where the customer is duplicated and one customer is sent as demand to "demand out" and further on to *Retailer Inventory*. The duplicate item which is still in the block will continue through port c of block A, then the demanded quantity of this customer will be read in block B and fed into block C which will create as many duplicates of the customer as there is demanded units by this customer. Block D will ensure that there is no demand sent to the central warehouse until the reorder point is reached and the demand is an even number of the batch size at this retailer. This works in the following way, the initial inventory at each retailer is set to R+Q and Block D will require Q units of demand before it will release the demand to the central warehouse. Consequently, the demand will be released every time the reorder point is reached. The demand from Block D will move forward as demand through “WDemandout” to the block *Central Warehouse*.

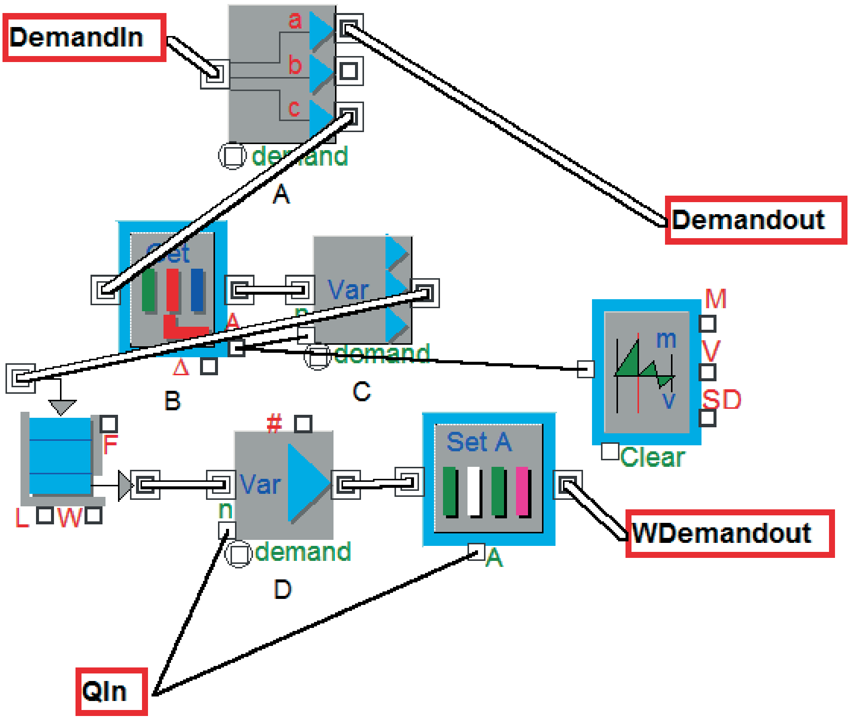


Figure 12. Simulation block Retailer Trigg.

The block *Retailer Inventory* can be seen in *Figure 13*. This block is a little more complex than the other blocks and since it was not modified in this thesis it will only be described conceptually and not in as much detail as the other blocks. This block starts, as mentioned earlier, with an inventory level of R+Q and the demand comes from the block *Retailer Trigg*. When the demand arrives, the first thing that happens is that the inventory level is controlled and if the full amount of the demand cannot be satisfied from stock it is backordered which will affect the calculated fill-rate negatively. When demand is backordered this block will keep track of how long and how many units it has backordered and then output this to enable calculations of the backorder costs. When the demand can be fulfilled, the demand and the requested demanded units are batched together and will exit this block, and subsequently, directly exit the simulation model.

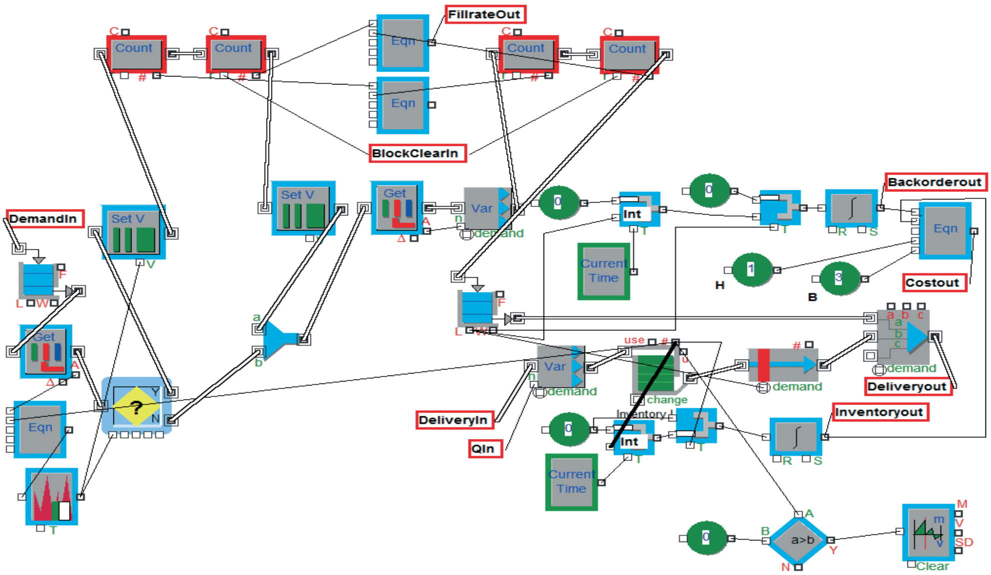


Figure 13. Simulation block Retailer Inventory.

In the block *Central Warehouse*, *Figure 14*, *t*he demand enters via "DemandIn" in the left of the figure. Module 1 will check the demand quantity to see if it can be fulfilled from the inventory. Depending on this it will be sent on different routes through module 2 which calculates the fill-rate at the central warehouse. The procedure to refill the central warehouse is similar to the one described in *Retailer Trigg*. Block A will duplicate the demand and send it to block B and block C. Block B needs exactly the amount of the batch size at the central warehouse to send away the demand to the outside supplier via "DeliveryOut". The inventory initial level at the central warehouse is assumed to be R+Q, and hence, the described procedure will order according to the (R,Q)-policy. This assumption is no restriction since the model studied is in steady state. The demand in block C will be in units and not batches and is served according to a First-Come-First-Served policy. As soon as there is a unit available in inventory this will be batched in block D together with one unit of demand and leave the *Central Warehouse* block.

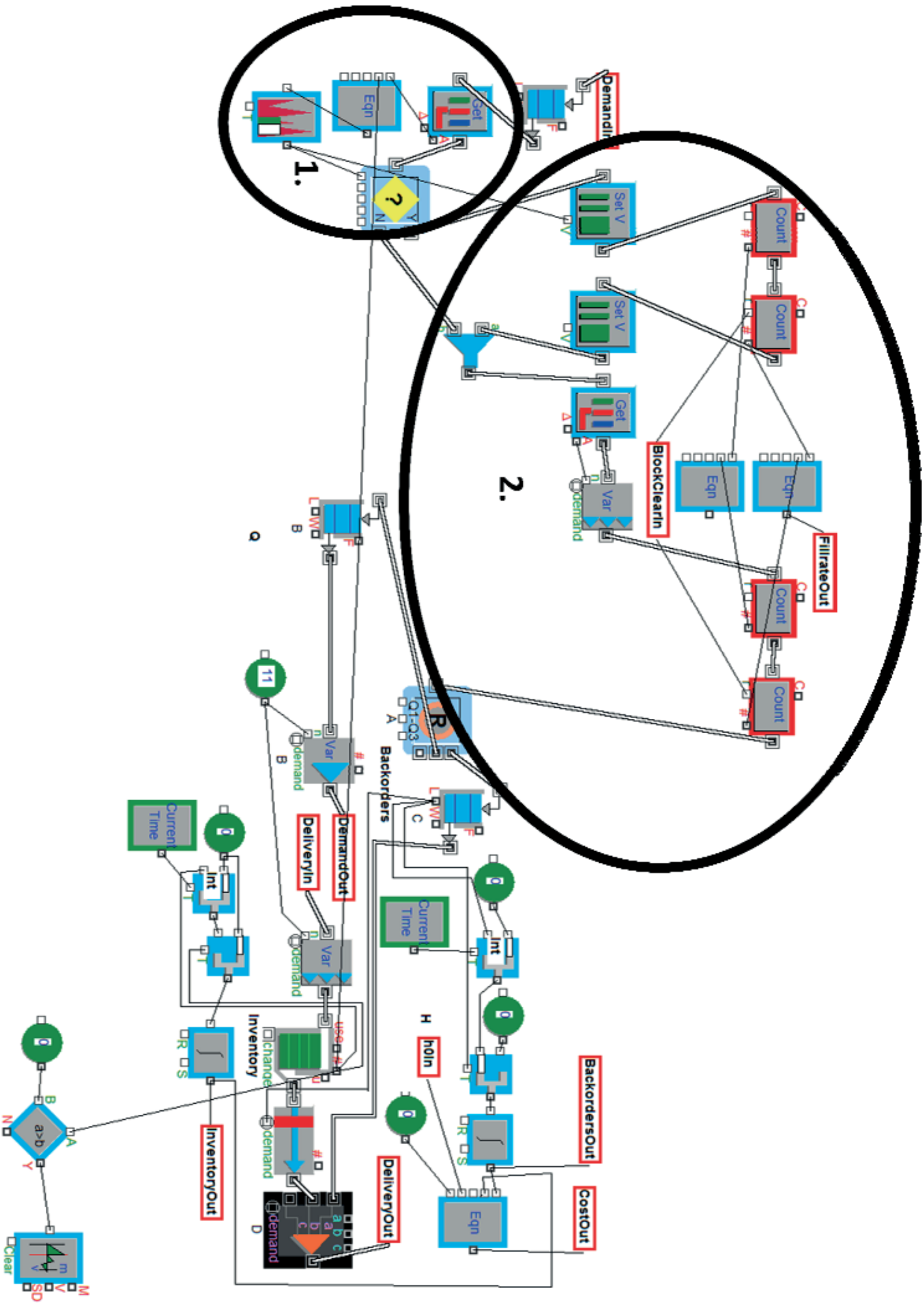


Figure 14. Simulation block Central Warehouse.

The units sent from the block *Central Warehouse* go to the retailers through the block *Complete Delivery*, *Figure 15*. These units are parts of a batch and this block can, depending on the settings in the model, batch them together in Block A. Consequently, the model allows both complete deliveries and partial deliveries. During this master thesis partial deliveries with the size of 1 have been used. This means that the central warehouse will send as much items of an order as it can to a retailer. The next block is Block B which illustrates the transportation with a constant transportation time. The blocks below block A and B calculate the inventory holding costs during the transport.

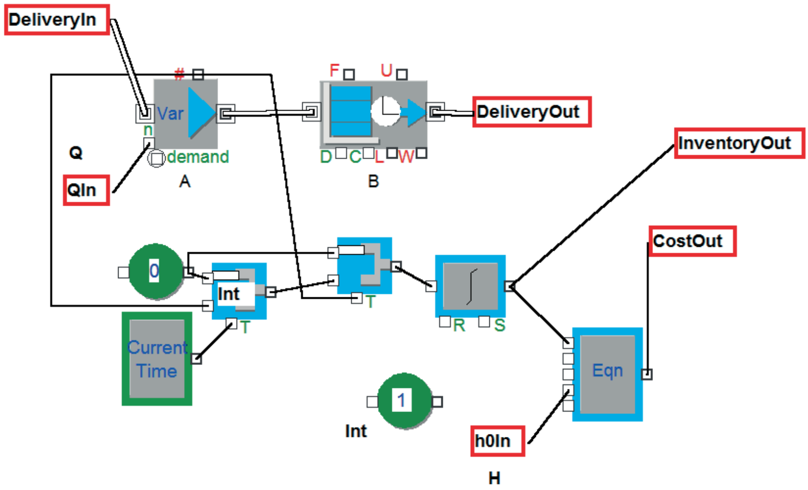


Figure 15. Simulation block complete delivery.

6.1.1 Assumptions made in the model

The simulation model builds on some assumptions. These assumptions are the ones making it possible to model the real inventory system and the reason why the model will differ from reality. However, the purpose is never to model the real system exactly as it is in reality. Instead the purpose is to model the system with as few parameters as possible but to still capture the essential dynamics of the simulated system. Hence, a simulation model should be simple enough so that it can be created but advanced enough to adequately estimate the parameters that will be studied.

The assumptions used in the simulation model of this master thesis will be discussed shortly in the following sections.

The customer demand is modeled as a compound Poisson distribution. The assumptions here are that the time between arrivals are modeled well by an exponential distribution and that the demand quantity can be modeled by any suitable distribution. (Adelson, 1966)

All installations use continuous review (R,Q)-policies, full backordering and no loss of customers.

A First-Come-First-Served policy is used at all installations and means, for instance, that even if retailer 1 has backorders and retailer 2 does not have any backorders, retailer 2's order will be served first at the central warehouse if it arrived there before retailer 1's order. This is, however, no restriction since this is the current policy used at Lantmännen (Hersner, 2013a).

The outside supplier has infinite stock and the transportation time from it to the central warehouse is deterministic and with no stochastic part. The transportation times between the central warehouse and the retailers are deterministic but the actual lead-times will be affected by stochastic delays due to stock-outs at the central warehouse.

6.2 Modification of the simulation model to incorporate emergency deliveries

The basic model cannot incorporate emergency deliveries, and hence, this feature needed to be added in the simulation model. During the first interview with Lantmännen the decision rule on when an emergency order is placed was investigated. Ultimately, the decision is made together with the end customer who is paying the extra cost associated with the emergency transport. The guidelines to the retailers are to have an open dialog with the customer and minimize the number of emergency shipments. The aim of these guidelines is that there should only be emergency transports when they are really necessary.

6.2.1 Modeling of emergency orders

Concerning the modeling approach for how the emergency orders are decided it was agreed that an order always was set as an emergency order if the demanded item was out of stock. Initially, it was discussed whether historical data from each retailer should be used to determine the percentage of the total orders which are emergency orders. Since these numbers later on were found to be unreliable it was agreed to follow the other approach.

6.2.2 Changes made in the model

In the basic simulation model four blocks were modified to implement the emergency orders. These blocks were *Retailer Trigg*, *Central Warehouse*, *Transportation from outside supplier* and *Complete Delivery.* The model which has emergency orders implemented will from now on be called the *extended model.* It is important to point out that emergency order will only be triggered at the central warehouse if there is a shortage here at the same time as there is an emergency order arriving from one of the retailers. In essence this means that it is only the retailers that can order emergency orders and not the central warehouse. The central warehouse will only do as they are told by the retailers.

When the demand enters *Retailer Trigg* in the basic model, see *Figure 12*, it is divided into two streams; one sending the demand to the *Retailer Inventory* and one sending replenishment orders to the *Central Warehouse.* In the extended model a new section, see *Figure 16,* was added which checks the current inventory level at the retailer. If the entire demand cannot be fulfilled the shortages will be satisfied as an emergency order. In the extended model, *section A* checks if the current stock at a retailer can fulfill the whole order at once. If this is possible, *block A* will send all orders as replenishment orders to the *Central Warehouse.* When not all the demand can be fulfilled from the current stock *block C* will route these parts through *section B. Block D* will route the backordered units through *port A, the upper port* or *port B, the lower port in this block. Port A* means that they will be sent as an emergency order and *port B* means that they will be sent as a replenishment order to the central warehouse.

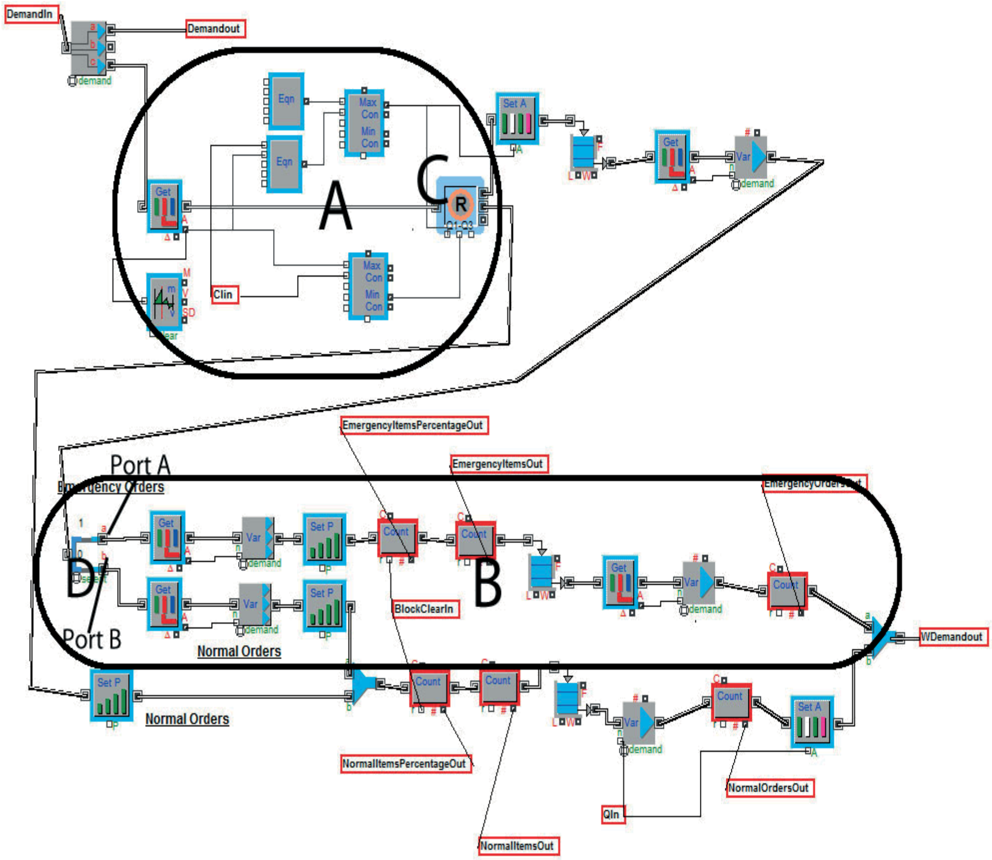


Figure 16. Extended simulation block Retailer Trigg.

The *Central Warehouse* in the extended model can be seen in *Figure 17* where *section A* is the new part added to the model. Essentially, this section performs the same operations as the *Retailer Trigg*. *Block C* creates a duplicate of the demand so that the model can send a replenishment order when the inventory level hits the reorder point. After the duplicate that will initiate replenishment orders is created, the priority is checked to see if it is an emergency order or a regular replenishment order. If it is an emergency order *section B* will perform the same test as *section A in Figure 16;* that is if the inventory at the *Central Warehouse* can fulfill the order or if some units needs to be sent as emergency orders to the outside supplier.

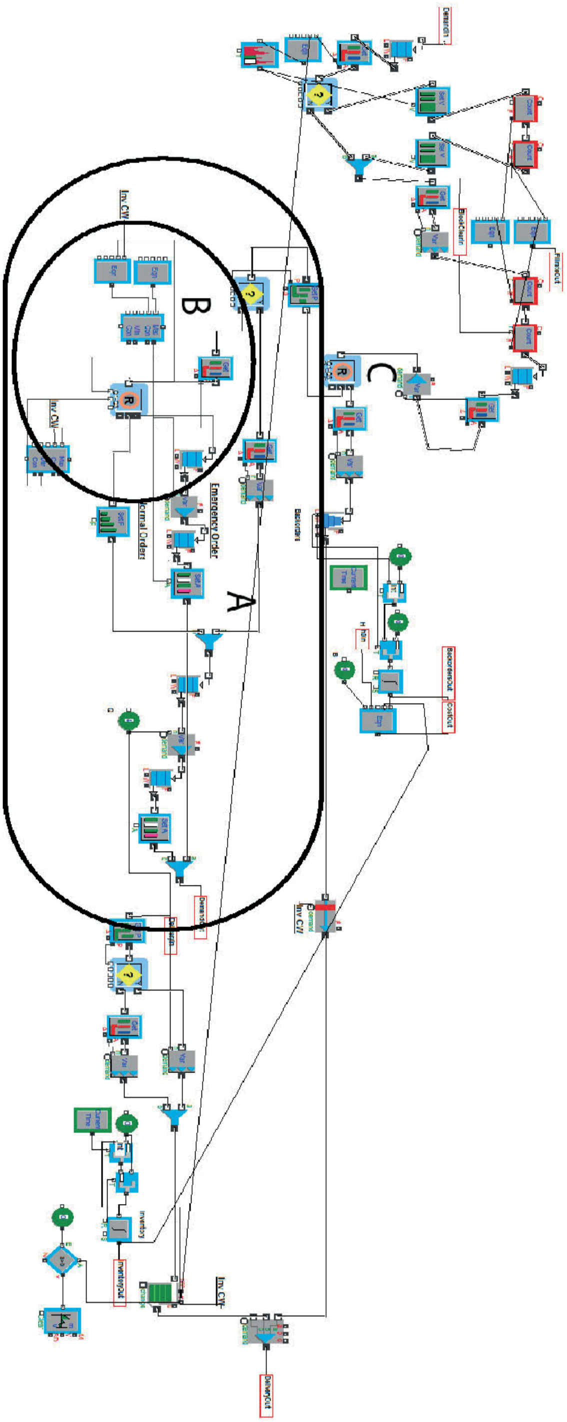


Figure 17. Extended simulation block Central warehouse.

If an emergency order is triggered at the *Central Warehouse* it will be sent to the block *Transport Outside Supplier*, see *Figure 18.* This block is a new block in the extended model which was not present in the basic model. The reason for this is that now two types of transports are required, emergency and normal transports, and hence, combining these two options into one block makes the model more transparent. This block will select transportation mode depending on the priority set at the *Central Warehouse*.

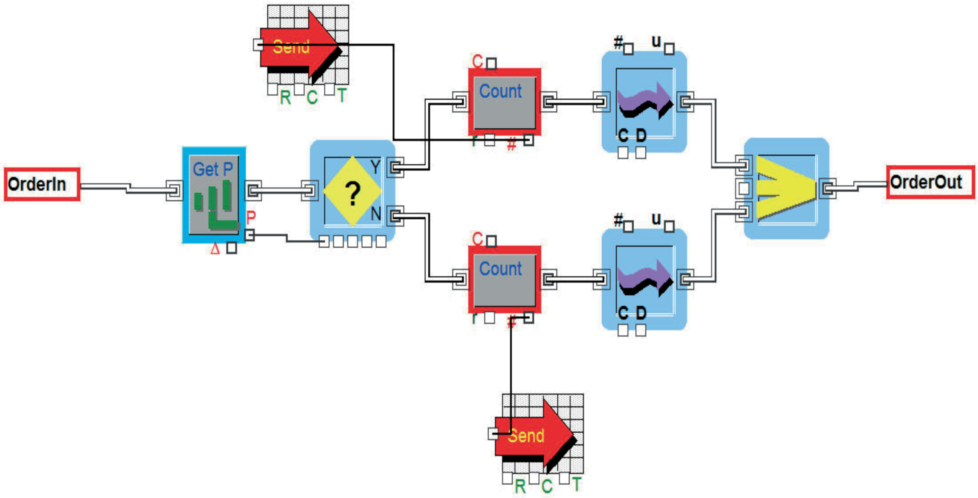


Figure 18. New block Transport Outside Supplier

The final changes were made in the block *Complete Delivery*, *see Figure 19.* The changes made in this block is very much like in the block *Transport Outside Supplier*, for each order coming in the priority is checked and if it is an emergency order it is sent via an emergency transport and otherwise with a normal transport.

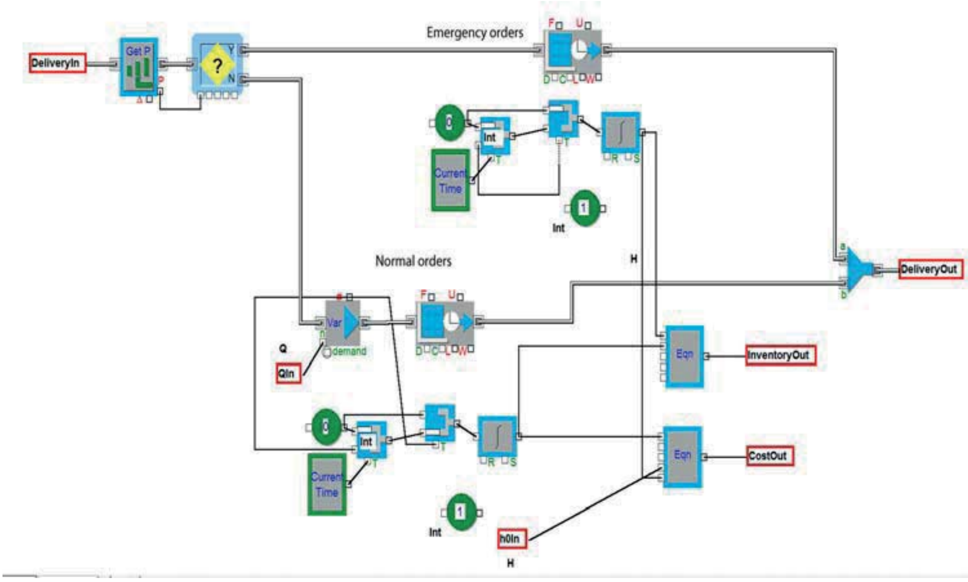


Figure 19. Extended simulation block Complete Delivery.

6.2.1 Validation of the extended model

Several measures were taken to ensure the internal validity of the extended simulation model. First of all, the model was built in small steps and every step was thoroughly checked. After the whole extended model was put together it was initially tested with the same settings as the basic model, i.e. emergency orders turned off, and they generated the exact same results. After that a series of tests to control the emergency orders was performed according to *Table 11* below. These tests were performed since it was simple to foresee what the results would be beforehand, and hence, easy to control if these results were met.

Table 11. Validation test run 1 of the extended simulation model.

Test	R[13]	Q[13]	DQty[13]	Emergency probability[13]	Emergency Lead-time[13]	Replenishment Lead-time[13]	Fill-rate Retailer[13]	Lead-time Retailer[13]
1	-4	4	4	1	0	14	**0**	**0**
2	0	2	4	1	0	14	**0.48**	**7**
3	2	1	4	1	0	14	**0.72**	**6.11**
4	-4	4	4	1	CW-0, R-4	14	**0**	**4**

The tests in *Table 11* were for all 10 retailers, Simulation time set to 301 000 days, time between arrivals was exponentially distributed with mean 365 days, the quantity demanded by customers was 4 units and the random seed was set to 100 for all arriving customer demands.

In test 1 in *Table 11* the reorder point (R) was set to -4 the batch quantity (Q) was set to 4, the demanded quantity at each retailer (DQty) to 4, the probability that a shortage becomes an emergency order to 1, the emergency lead-time to 0 and the replenishment lead-time to 14. If R is set to -4 there will always be a shortage since no regular replenishment order will be generated until the inventory level is -4. This is reflected in the fill-rate of 0. Since the fill-rate is 0 all orders will be shipped as emergency orders which can be seen in the results that the lead-time from the central warehouse to the retailer is 0. Continuing to test 2 in *Table 11*, the reorder point was 0, the batch quantity 2 and the demanded quantity 4 which indicates a fill-rate of 50% and that approximately half of the items would be sent as emergency orders and half as replenishment orders. The result from the simulation confirms this as the fill-rate becomes 0.48% and the lead-time 7 days. Test 3 and 4 are calculated in the same way.

The purpose of these tests was to simulate simple cases were the fill-rate and the lead-time could be foreseen. Essentially, they all follow the logic that since the demanded quantity is always 4, the quantity that can be

[13] R = reorder point, Q = batch quantity, DQty = constant demanded quantity for each arriving customer at the each retailer, emergency probability is the probability that a shortage becomes an emergency order, emergency lead-time is the planned lead-time between the central warehouse and the retailer for an emergency order and replenishment lead-time is the same as emergency lead-time but for a regular replenishment order.

delivered directly from stock at the retailer is R+Q. This is true since the arrival rate is set fairly low, 365 days and the planned replenishment lead-time for a delivery is set to 14 days, which suggests that very rarely will there be more than one order outstanding.

Concerning the internal validity of the base model it has been used in several master theses before and also research performed at Lund University, Faculty of Engineering. Therefore, the internal validity of the basic model is very high. Also the internal validity of the extended model is high since it performs exactly as the basic model when they have the same settings and it also performs as expected in all of the test runs performed.

The final step to ensure the external validity of this model is to compare the results with the reality. This was done by comparing the results from the simulation for three items, both at the central warehouse and at the retailers (16 different), with the real life values in the inventory system. The values compared were number of emergency orders per year, number of regular replenishment orders per year, fill-rate and holding cost. These values were sent to Lantmännen and they verified them as being correct.

7. Simulations

This chapter describes how the simulations were performed in this Master Thesis. At first, the approach to determine a valid simulation time is described, after that the input data to the simulation model and how the simulations were performed is communicated. Finally, the output data and how the uncertainty is handled in the model are discussed.

7.1 Simulation time

The simulation time is a very important factor when performing simulations and needs to be balanced against the time available for performing the simulations study. Long simulation times will generate results with less uncertainty but the time to perform the simulation can then be extremely long. The challenge is to choose a simulation time which is long enough to provide low standard deviations for the studied parameters but not too long causing the project to run out of time.

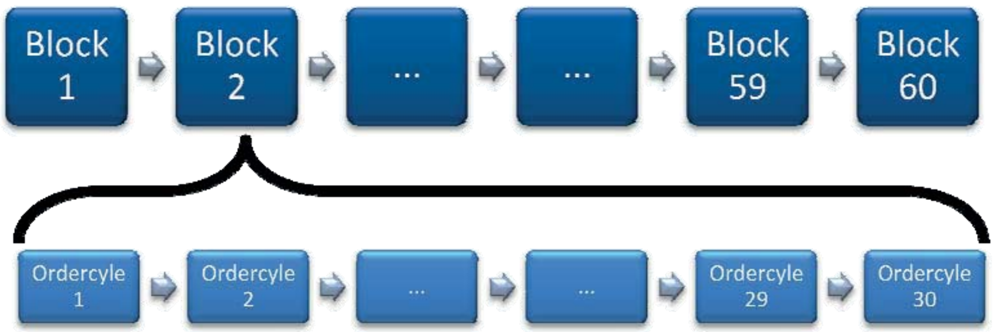


Figure 20. Illustration of the 60 simulation blocks and their 30 order cycles.

The simulation model used is built on so called "time blocks" with a certain length, a block length. If the block length is, for instance, 15 000 days then the simulation model will collect statistics regarding the parameters that are studied in the model at the end of each block. At the end of the simulation these values are used to calculate the mean of the parameters and the associated standard deviations. When the block length is chosen it is important that it consists of a sufficient amount of order cycles, where an order cycle is defined as the batch quantity Q divided by the mean demand. The reason for this is to make sure that the different blocks can be considered to be independent of each other. After a discussion with the supervisor of this master thesis a block length which consists of 30 order cycles for the retailer with the longest order cycle was chosen. *Figure 20* illustrates how the simulation time consists of 60 blocks which each consists of 30 order cycles.

The parameters studied in this master thesis are the expected costs, fill-rates, inventory levels, emergency orders, replenishment orders, total orders, items sent as emergency orders, items sent as replenishment orders, total amount of items shipped, total CO_2-emissions, the emergency orders proportion of total CO_2-emissions at each retailer, and also the total of these parameters. When the block length was decided the next matter was to decide how many blocks to study; the amount of blocks directly affects the uncertainty of the studied parameters. The approach for doing this was to set the simulation time as a number of block lengths, in this case 60 blocks. Since the model uses the first block as a warm-up period and throws the value from this block away 61 blocks was chosen for the model. Another possible approach is to set the simulation time so that the ratio between the mean and the standard deviation for the studied parameters are less than a particular value. This ensures that all the studied parameters have low uncertainty. This latter approach was tested at first, but already at the second item it showed to generate too long simulation times. Consequently, this approach was not a possible alternative in this project.

7.1.1 No support for several processor cores in Extend

A factor which unfortunately extends the simulation time is the fact that Extend 6.0 cannot handle more than one core. This is also true for later versions, i.e. Extend 8.0. As a consequence a simulation performed on a computer with a dual core processor, which almost all low to medium end computers have today, will take twice the time since only one of two cores of the processor is used. For high end computers, as the one used in this master thesis which have four cores, the simulation time is extended by a factor of four. Hopefully, this issue will soon be resolved by the software company behind Extend.

7.2 Input to the simulation model

The simulation model needs many input values which vary for each item. To be able to modify the models easily, Dynamic Data Exchange (DDE) links between Excel and the simulation model was set up for all the values the model needed as input. A DDE link in the simulation model will require the specific workbook linked to it to be open when the simulation model is open. If a value is changed in the workbook this same value will be changed in the extend model. By this approach, four files for each item was set-up in two separate folders, one folder for single-echelon and one for multi-echelon. Each folder contained one simulation model and one Excel workbook with input parameters for the model. The input data to the model for each retailer and the central warehouse is shown in *Table 12*.

Table 12. Input parameters to the simulation model.

Parameter	Description
Q	Batch quantity.
R + Q	Reorder point + batch quantity.
p	Shortage cost calculated by the excel model.
h	Holding cost given by Lantmännen.
L	Planned lead-time in days.
EmergencyL	The planned lead-time for an emergency order.
Emergency probability	The probability that a shortage at the retailer will be sent as an emergency order (set to 1 always, see Chapter 5).
Lambda	Fitted lambda from the excel model.
Max items generated	Value which determines if a retailer is active or not, set to 0 items if not active and very large number i.e. 1E+40 if the retailer is active.
Block length	Time length of each block in the simulation.
Simulation time	Inserted at start of the simulation via an external VBA-macro setup to remotely run the simulations automatically without user interference.
CO_2-emissions per item	These are the calculated CO_2-emission in grams per item for both emergency and replenishment items.
Empirical compounding distribution matrix	Matrix which specifies the probability mass function for the quantity demanded by a single customer.

7.3 Different lead-time set-ups

The planned lead-times currently used for the SCP-model in the ERP-system are 4 days between all retailers and the central warehouse. This is not entirely correct according to how the real system behaves. The actual planned lead-times differ between geographical locations. To the north of Sweden the planned lead-time is 4 days since the transportation time to these locations is one day longer than in the south of Sweden, where the planned lead-time is 3 days. Consequently, for many retailers the planned lead-time in the SCP system is set to be longer than it actually is. This setting is made because Lantmännen wants an increased safety stock at the retailers. Using a fictitious lead-time is not theoretically correct and therefore two sets of simulations are performed, one with the planned lead-times used in the inventory system, and one with the planned lead-times found in the ERP-system.

7.4 Running the simulations

Since a large number of simulations are run, i.e. 424 (106 items * 4 simulations), it would be quite tedious to manually start a simulation and wait for it five minutes or so before it is completed, save it and start the next one. The procedure is also very predictable, meaning that there will not happen anything out of the ordinary during any of the simulations which a human needs to attend and analyze; the only interesting parts are the final results from all the 424 simulations. Therefore, a VBA-macro was programmed to open the model and the Excel workbook containing the input parameters. The macro then sets the simulation time, waits until the simulation is finished, saves everything and then opens the next model and performs the same procedure. By the use of this VBA-macro the simulations could be performed remotely.

7.5 Output data from the simulations

The output from a simulation run include the estimated holding costs, fill-rates, inventory levels, emergency orders, replenishment orders, total orders, items sent by emergency orders, units sent by replenishment orders, total amount of units shipped, total CO_2-emissions, the emergency orders' proportion of total CO_2-emissions at each warehouse, the total of these parameters and the corresponding standard deviation for each parameter.

All mean values are expressed in per day, for instance mean inventory per day, if they are not percentages like the fill-rate. These parameters were sent directly to Excel via Active-X links at the end of each simulation.

8. Results and analysis

This chapter describes the results from the study. The analysis of the observed results is presented along the way. First, the simulations of the inventory system with the actual lead-times are reported. Secondly, the results are analyzed and different findings are discussed. Thirdly, the results from the simulation with the lead-times currently used in the SCP model are reported and compared to the results for the actual lead-times in the inventory system. Finally, the special aspects of Lantmännen's inventory system and how it differs from other companies are discussed.

8.1 Comments on lead-times between central warehouse and retailers

The actual planned lead-times for replenishment orders from the central warehouse to the retailers at Lantmännen are today 3 or 4 days; four days to the retailer in the north of Sweden and three days for those in the south. The lead-time used in the ERP-system is, however, set to four days for replenishment transports to all locations within Sweden. This is done to better achieve the fill-rate targets. Setting the lead-time to four days instead of three days leads to higher reorder points and larger safety stocks which helps the SCP model to provide higher fill-rates. The reason why this happens is that when the lead-time is increased so is the demand during the lead-time. When the demand during the lead-time is increased the safety stock to prevent stock-outs needs to be increased to achieve the same fill-rate. Adding a day to the planned lead-time in this way may or may not work well for Lantmännen and their inventory system, but when faced with a new inventory set-up it is not easy to know how many days to add to achieve the right fill-rate level. Hence, arbitrarily adding one day of safety time to the lead-time is not a theoretically sound approach to use. Increasing the lead-time with one day will inevitably also add more inventories, and hence, increase the holding costs.

The planned lead-times found in the inventory system are 3 and 4 days. Consequently, these figures are more accurate to use for the analytical models than setting all lead-times to 4 days. Consequently, by using the actual lead-times in the analytical models the results will give a more generalized image of how the SCP model performs versus the MEM model in a multi-echelon inventory system.

Since Lantmännen uses four days in the SCP model this scenario is also analyzed in *Chapter 8.4.*

8.2 Simulation of the planned lead-times of three and four days

The results from the simulations with the planned lead-times of three and four days can be found in *Table 14* and the parameters are described in *Table 13*. The fill-rate as a straight mean has increased by 8.31%, the fill-rate as a mean weighted with the demand has increased 34.39%, the holding cost has decreased by 18.14%, items sent with emergency transport has decreased by 96.77% and the CO_2-emissions from the transportation in the whole inventory system is decreased by 56.99%. This indicates that there are a lot for Lantmännen to gain on the environmental side by switching from the SCP model to the MEM model. During this project different values were received for the emergency order by air. To not overestimate the benefits of the MEM model regarding CO_2-emissions the lowest value, 0.3 kg CO_2 per kg sent goods, for the emergency orders sent by air have been used during the simulations. To fully investigate the benefits a sensitivity analysis is performed in *Chapter 8.4* with the highest value received, 1.5 kg CO_2 per kg sent goods.

Table 13. Description of the result parameters.

Parameter	Description
Fill-rate	Mean of the fill-rate for every retailer.
Holding cost	Sum of all expected holding costs for every retailer and the central warehouse. (SEK/day)
Emergency items, percentage of total	Expected proportion of the demanded units satisfied by emergency deliveries. The value is calculated as a straight mean over every retailer.
Emergency Items	Sum of the expected number of units shipped as emergency deliveries for every retailer. The unit is [items/day].
Total CO2-emissions	Sum of all CO2-emissions for every retailer. The unit is [CO2-emissions in gram/day].

Table 14. Results from the simulation with the actual lead-times displayed as averages per day.

	Fill-rate (straight mean)	Fill-rate (weighted mean)	Holding Cost	Emergency items, percentage of total	Emergency Items	Total CO2-emissions
SCP	91.94%	73.22%	169.25	8.07%	2.07	305.52
MEM	99.58%	98.40%	138.55	0.43%	0.07	131.41
Diff (%)	8.31%	34.39%	-18.14%	-94.73%	-96.77%	-56.99%
Mean Target Fillrate		98.76%				

8.2.1 Increased fill-rate

When changing the control of an inventory system to multi-echelon control instead of single-echelon control the inventory the inventory tends to be pushed from the central warehouse towards the retailers. This leads to increased amount of items in stock at the retailers while the stock level at the central warehouse instead is reduced. As an effect of using multi-echelon control instead of single-echelon control in this case study, the fill-rate at the retailers are, on average, increased by 8.3% for the studied items. However, by doing this stock transfer and moving the stocks closer to the end customers, the inventory level at the central warehouse gets lower along with the fill-rate there. Since the fill-rate at the central warehouse only estimates how well served the internal customers are, i.e. retailers, this is not significant for the performance of the company as a whole. Therefore, the value of the fill-rate in *Table 14* only concerns the fill-rate at the retailers.

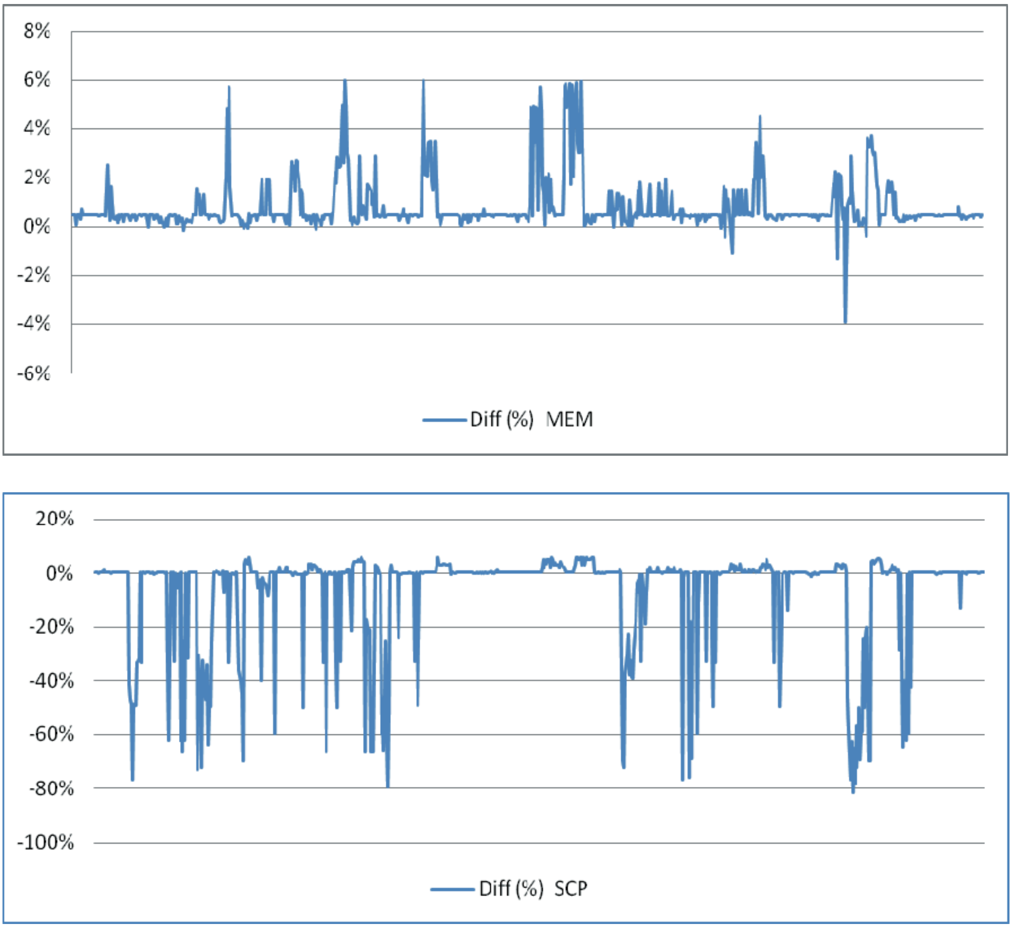


Figure 21. Difference between target fill-rate and the fill-rate achieved during the simulation, per retailer and item.

Analyzing the fill-rate not only the straight mean is of importance. It is also interesting to see how the values are distributed. In *Figure 21* the difference between the target fill-rate and the fill-rate achieved during the simulation is plotted for SCP and MEM. The value on the y-axis is the difference from target fill-rate in percent. The value on the x-axis is the achieved fill-rate for each retailer and item combination studied. The figure clearly shows that MEM is much more consistent in achieving the target fill-rates.

Table 15. Key figures for the fill-rate between the SCP model and the MEM model.

Key figures	**SCP**	**MEM**
Mean of difference from target fill-rate (%)	-6.81%	0.83%
Mean of weighted difference from target fill-rate (demand, %)	-24.44%	0.74%
Max positive difference from target fill-rate at retailers (%)	6.00%	5.99%
Mean of positive difference from target fill-rate at retailers (%)	1.17%	0.85%
Max negative difference from target fill-rate at retailers (%)	-81.40%	-3.92%
Mean of negative difference from target fill-rate at retailers (%)	-29.46%	-0.57%

To further analyze the fill-rate results the values in *Table 15* above were calculated. It shows that the mean difference from target fill-rate weighted with the average demand is actually -24.44% for the SCP model. Consequently, if the fill-rate is defined as service fulfillment to the customers based on the amount of demand it is much worse than the straight mean. The MEM model on the other hand performs just a little bit better for the weighted mean than for the straight mean.

The next four values in *Table 15* shows the max positive and negative difference and also their means. These values indicate that the two models perform equally on the max positive difference and its mean, but this should come as no surprise. If the values for target fill-rate are more carefully studied one sees that almost all of them are close to 99% or 99.5%. Therefore the mean positive difference is the same for the two models. For the max positive difference this occurs when one of the items with the lowest target fill-rate, 94%, has a reorder point which makes the fill-rate 100%. The max negative difference and its mean are much more interesting figures. It shows that the SCP model misses the target fill-rate with at most 81.4% whereas the MEM model misses it with at most 3.92%.

For the mean negative difference the SCP model has a value of -29.46% and the MEM model -0.57%.

This analysis shows that the SCP model is much more volatile in the fill-rate fulfillment. It gets a rather good average of the fill-rate but this average consists of many fill-rates that are low and these are compensated for with high ones. The MEM, on the other hand, is more consistent and do not deviate so much from the target fill-rates.

8.2.2 Lower holding and transportation costs

The cost used for the comparisons between the SCP model and the MEM model are the holding costs of the items kept in stock. Since the holding costs are affected by the total value of articles kept in stock, these costs will be decreased if the value of the total stock in the central warehouse and at all retailers together is decreased. For the items simulated the total holding costs decreased with 18.1% when comparing the MEM model with the SCP model.

An additional cost affecting the inventory system, which also could be of interest studying, is the transportation cost. While Lantmännen has the same costs for both emergency orders and replenishment orders for land transport, and do not want to disclose these figures, these costs will not affect the results. However, there are a fair amount of emergency orders sent per year and this will affect the cost of the inventory system.

Normally, emergency orders have higher transportation costs than replenishment orders due to less utilization of transport space and more expensive means of transportation. The transportation cost affects the total cost reduction when comparing the two controlling systems and by incorporating it in the calculations it can be possible to show more cost reductions. A more thorough analysis of the transportation cost is found in *Chapter 8.5*.

8.2.3 Less emergency orders and CO_2-emissions

The larger stock levels and the higher fill-rates obtained from the multi-echelon control of the inventory system result in a decreased need of sending emergency items. As the risk of shortages in the retailer inventories is reduced when the stock levels are increased, the need for emergency shipments is also decreased. Since the decision of which means of transportation to send the emergency orders with is decided by the fact that they have to reach the customer the next day, the mode chosen is often less environmental friendly than the mode used for replenishment orders. Hence, when sending less emergency orders the CO_2-emissions will also be reduced. For the simulated items the total amount of CO_2-emissions for transportation in the inventory system was decreased with 57.0%. Depending on what kind of emergency shipment it is and the location of the retailer, the emissions per shipment will vary. A complete list of CO_2-emissions per item for replenishment orders and emergency orders can be found in *Appendix I*. For the retailer further north than the distribution regions of Karlstad, Uppsala and Örebro, air transport is required to enable the planned emergency lead-time of one day at Lantmännen. Also emergency transports to Visby and Hemse on Gotland, is transported by air. The emergency shipments performed by air emit more CO_2 per kg transported goods than road transport. Hence, the possibility to reduce these emergency shipments also results in less CO_2-emissions when sending items as replenishment orders with truck. Concerning the emergency shipments transported on road, these also affect the amount of CO_2-emissions. Since the trucks used for emergency shipments usually have lower capacity utilization compared to the planned transportation of replenishment orders, the emission for the items sent with these trucks are higher per kg transported freight. Hence, both modes used for emergency shipments could be changed to regular, planned road transport with higher capacity utilization, and thereby reduced CO_2-emissions. Sending planned shipments, i.e. replenishment orders in the Lantmännen case, simplifies for the transportation company to utilize the freight space better and reduce the emission. This applies for other modes of transportation as well, since the more environmentally friendly a transportation modes is the slower it usually is, and the more planning in advance is required.

The results in *Table 14*, shows that the proportion of emergency deliveries went from 8.1% with the SCP model to 0.4% with the MEM model. This reduction enabled the system to on average save 57.0% of the total CO_2-emissions. The CO_2-emissions from emergency orders was 73.8% of the total CO_2-emissions for the SCP model and the figure for the MEM model was 11.0%. This shows that there is a large potential to lower the CO_2-emissions in a multi-echelon inventory system by using the MEM model instead of the SCP model.

8.3 Results and analysis with regard to the chosen strata

During the stratification five different parameters were chosen to base the stratified selection on. These parameters were believed to have an impact on the three aspects which are primarily measured during this project, namely fill-rate, holding cost and CO_2-emissions. *Table 16* shows the results for the intervals chosen for the parameters obtained from the simulation for the SCP and the MEM model. The assumptions made during the stratification were the following:

- **Fill-rate**
  - The standard deviation divided by the mean (σ/μ) and the mean demand should have an impact on the fill-rate and that the fill-rate would have an impact on the CO_2-emissions.
- **Holding cost**
  - Expensive items should generate more cost savings than less expensive items.
- **CO_2-emissions**
  - Emergency orders sent by air should have a greater impact on the CO_2-emissions than emergency orders sent by truck.
  - Heavy items should have greater impact on the CO_2-emissions than light items.

Table 16. Results from the stratification per parameter.

	Retailers in interval	Diff from target fill-rate SCP	Diff from target fill-rate MEM	Holding cost SCP	Holding cost MEM	Diff(%)	CO2-emissions SCP	CO2-emissions MEM	Diff(%)
Std/mean									
0 - 1	**20**	3.58%	1.86%	4.24	4.24	**-0.15%**	8.04	9.15	**13.85%**
1 - 5	**713**	-7.10%	0.80%	135.32	129.64	**-4.20%**	297.48	122.27	**-58.90%**
EO									
Air mode	**469**	-5.61%	0.80%	66.13	69.58	**5.21%**	65.19	46.43	**-28.78%**
Road mode	**264**	-8.95%	0.88%	73.43	64.30	**-12.44%**	240.33	84.99	**-64.64%**
Weight (kg)									
0 - 25	**720**	-6.61%	0.80%	129.90	124.91	**-3.84%**	85.03	52.43	**-38.34%**
25 - 500	**13**	-17.82%	2.44%	9.66	8.96	**-7.23%**	220.49	78.98	**-64.18%**
Mean									
0 - 5	**120**	-0.94%	0.77%	37.87	31.03	**-18.06%**	7.56	7.11	**-5.84%**
5 - 20000	**613**	-7.96%	0.84%	101.70	102.84	**1.13%**	297.96	124.30	**-58.28%**
Unit cost (SEK)									
0 - 100	**452**	-9.59%	0.45%	14.67	26.22	**78.70%**	59.36	28.59	**-51.84%**
100 - 500	**202**	-4.60%	0.83%	30.45	36.51	**19.90%**	222.08	77.91	**-64.92%**
500 - 1000	**79**	3.43%	2.98%	94.44	71.14	**-24.67%**	24.07	24.91	**3.49%**

8.3.1 Fill-rate, implications from strata

The comparison of the two models on the fill-rate parameter for the two intervals of std/mean and mean demand shows that the MEM model performs better than the SCP model for all intervals. For the mean demand there is no significant difference between the two models. Studying the std/mean, the MEM model fulfils the target fill-rate better for both intervals. For the items with a std/mean which less than 1 the MEM model overestimates the target fill-rate by 1% more. This difference is, however, very small and if one takes into consideration that only 20 retailers are studied for this value it might very well lie within the margin of error.

Furthermore, *Table 16* shows that the MEM model is better on achieving the target fill-rate for all intervals compared to the SCP model.

8.3.2 Holding costs, implications from strata

An interesting result appears when studying the holding costs. The MEM model only lowers the costs for the high valued items and increases it for the low valued items. The reason why this happens is because the SCP model has a low fill-rate for the two lower intervals of unit cost compared to the MEM model. What this means is that the SCP model somehow controls high-valued items differently from low-valued items which results in higher inventories for these items and higher fill-rates.

8.3.3 CO_2-emissions, implications from strata

The hypothesis for the CO_2-emissions was that air transport would have larger impact than road transport on this parameter. The results from the strata show that in this particular case study they did not have that large impact. The reason for this is that the SCP model on average has fulfilled the fill-rate better for the item and retailer combinations where the emergency deliveries are transported by air. Another reason is that the value used for air transports during the simulations did not differ very much from emergency transports sent by truck. Since this value was quite uncertain, a sensitivity analysis on the connection between air transports and the CO_2-emissions is presented in *Chapter 8.4.*

If instead the weight is studied the assumption that heavier items have will have a greater impact on the CO_2-emissions are confirmed in the results. This observation will be further analyzed in *Chapter 8.4.3*

8.4 Uncertainties in the CO_2-calculations

Since the information about CO_2-emissions varies depending on the source used and the chosen transportation mode, sensitivity analyses were performed on these parameters.

8.4.1 Changing the parameter for CO_2-emission caused by air transport

In the first step of the sensitivity analysis the uncertainty of the CO_2-emission caused by air transport was tested. The purpose of this test was to determine how much the variation of CO_2-emissions per kg freight sent affected the level of CO_2-emission caused by all transportation in the system. The sensitivity of the CO_2 input parameter for air transport was tested since it is seen as an uncertain value used in the analysis of this master thesis. The parameter was tested for two different values obtained from Lantmännen's transportation companies; the lowest value of 0.3 kg CO_2 and the highest value of 1.5 kg CO_2 per kilo freight sent to any destination within Sweden. The results from scenario 1 with CO_2-emissions of 0.3 kg can be found in *Table 17* below. This value is also used in the main analysis of this master thesis to ensure that the difference in CO_2-emission between the MEM model and the SCP model shows the lowest possible effect.

Table 17. Total CO_2-emission (gram/day) caused by transportation when the emissions for flight are set to 0.3 [kg CO_2/kg goods sent]. The result differs slightly from the results from the simulations due to different rounding errors between Extend and Excel.

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	80.28	225.72	306.00
MEM	117.13	14.36	131.49
Diff (%)	45.90%	-93.64%	-57.03%

To give an indication of how a variation in the emission from air transport affects the total CO_2-emissions in the transportation system a comparison between the results found in *Table 17* and results from scenario 2, found in *Table 18*, was done. Scenario 2 is the case with a value of 1.5 kg CO_2-emissions per kg sent freight is used.

Table 18. Total CO2-emission (gram/day) caused by transportation when the emissions for flight are set to 1.5 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	80.28	267.73	348.01
MEM	117.13	27.24	144.37
Diff (%)	45.90%	-89.82%	-58.51%

Table 19. Comparison of average number of emergency orders sent by air and by truck per day.

	Emergency orders by truck	Emergency orders by air	Diff (%)
SCP	0.31	0.05	-83.63%
MEM	0.04	0.01	-83.95%

As can be obtained from *Table 17* and *18* the total CO_2-emission in the transportation system is only slightly affected when the CO_2 input value for emergency orders by air is changed. A five times bigger value, than the minimum value used, barely increased the CO_2-emissions from the system.

The reason for this is that the amount of emergency orders sent by air per day is much lower than the amount of emergency orders sent by truck. Approximately there are 84% less emergency orders sent by air than by truck, see *Table 19.* In comparison to the CO_2-emissions from the total amount of emergency items sent per day in the system the amount of emergency items sent by air transport is low, which results in the low influence when varying the input parameter for air transport. *Table 20* and 21 below show the impact of the CO_2-emissions for both 0.3 kg and 1.5 kg when only locations where emergency orders are transported by air are included. Consequently, this figure will have a great impact on the items sent by air. If only considering this system in isolation the reduction compared to the whole system will increase with approximately 30%.

Table 20. CO2-emission (gram/day) caused by transportation when only emergency orders sent by air transport is included. The emission is set to 0.3 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	17.05	10.69	27.74
MEM	18.02	3.26	21.29
Diff (%)	5.71%	-69.48%	-23.26%

Table 21. CO2-emission (gram/day) caused by transportation when only emergency orders sent by air transport is included. The emission is set to 1.5 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	17.05	52.70	69.74
MEM	18.02	16.15	34.17
Diff (%)	5.71%	-69.36%	-51.01%

Resolved from this analysis is that the CO_2 input parameter for emergency orders sent by air transport affects the total emission modestly in this case. Hence, the size of this parameter is not seen as critical when it comes to evaluating the CO_2-emissions from the total transportation system of the

MEM model compared to the SCP model. The reduction of CO_2-emissions remains about the same for the system in both cases.

8.4.2 All emergency transports either by air transport or by road transport

Calculations were done where all emergency transports were set to be either by air transport in one case or by road transport in another case. This analyzes was performed to provide an illustration of the behavior of emergency orders in the inventory system and how the mode choice will impact the total CO_2-emissions. The calculations shows a generalization of how analogous inventory systems with similar low, frequent demand can behave if they only contain emergency orders sent by air transport, road transport or a different combination of the two than in the inventory system of Lantmännen. For instance, a company with a central warehouse in Sweden and retailers spread all over Europe would probably use air transportation for all emergency transport to be able to deliver the spare parts within one day to its customers.

The results when all emergency orders are set to be by air transport can be found in *Table 22.* In *Table 17* above the results from the original case is found which is used for comparison.

Table 22. CO2-emissions (gram/day) when all emergency orders in the system are sent by air transport and the CO2-emission is set to 0.3 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	80.28	612.12	692.40
MEM	117.13	34.27	151.40
Diff (%)	45.90%	-94.40%	-78.13%

Table 23. CO2-emissions (gram/day) when all emergency orders in the system are sent by air transport and the CO2-emission is set to 1.5 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	80.28	3060.61	3140.89
MEM	117.13	171.35	288.48
Diff (%)	45.90%	-94.40%	-90.82%

As can be obtained from *Table 22* the CO_2-emissions are decreased by 78.13% when all emergency orders are sent by air transport, which is more than in the original (reduction of 57.03%). This is due to the fact that air transport has higher emissions than road transport and when the amount of air shipments increases the total emission also increases. If the value of 1.5 kg per transported kg goods is used the reduction is even more significant, namely 90%, see *Table* 23.

In Table 24 below the corresponding result when all emergency transports are sent by road transport is stated.

Table 24. CO2-emissions when all emergency orders in the system are sent by road transport and the CO2-emission is set to 0.107 [kg CO2/kg goods sent].

	CO2 replenishment (g)	CO2 emergency (g)	CO2 total (g)
SCP	80.28	218.79	299.07
MEM	117.13	12.25	129.38
Diff (%)	45.90%	-94.40%	-56.74%

Table 24 shows that the CO_2-emission is reduced by 56.74% when all emergency orders are sent by road transport. Since most emergency orders in the case at Lantmännen already are sent by truck, this number just deviates slightly from 57.03% as obtained in the original case.

Even though one cannot with certainty generalize these figures to other systems they are a strong indication that implementing the MEM model can significantly decrease the CO_2-emissions for freight transports. Especially if the emergency orders are shipped by air. The figure of 1.5 kg per transported kg is the value for air transport well to air from Malmö to Umeå in Sweden, approximately 1000 km. This is approximately the same distance as from Malmö to the middle of Europe. Therefore this figure can be seen as a good approximation for a company having a central warehouse in Sweden and retailers spread over Europe. Such a company would then have the possibility to reduce the CO_2-emissions with approximately 90%, which would be a great benefit for the environment.

8.4.3 Parameters affecting the CO_2-emissions

In *Table 25* the distribution of the CO_2-emissions between different weight intervals can be seen for the SCP model and the MEM model. The distribution does not significantly differ between the two models. However, between the different weight intervals the differences is evident. For the SCP model 72% of the CO_2-emissions are emitted of the items in the weight interval 5-30 kg whereas this interval only consists of 6% of the items. For the interval 0-0.5 kilos the difference is the other way around and 76% of the items emit only 8% and 13% of the total CO_2-emissions for the SCP respectively the MEM model. This indicates that the heavy items have a significant impact on the results. This is logical since all the CO_2-emissions linearly depend on the transported weight for all transportation modes.

Table 25. Distribution of CO2-emissions between different items.

Weight Interval, kg	Items of total (%)	SCP CO_2 of total (%)	MEM CO_2 of total (%)
30-100	2%	4%	8%
5-30	6%	72%	61%
1-5	9%	2%	4%
0.5-1	7%	14%	14%
0-0.5	76%	8%	13%

If the interval 5-30 kilos is analyzed more in detail it is found that item 5 has a very large impact on the whole system. For the SCP model item 5 represents 68% and for the MEM model 50% of the total CO_2-emissions. This is a very significant value and it shows that item 5 has a disproportionate impact on the CO_2-emissions of the inventory system. The reason why this item has such a huge impact is the heavy weight but also the fact that it has a rather high mean demand compared to other items with weight above 5 kg. Consequently, an important fact have been identified; when trying to reduce the CO_2-emissions of an inventory system items with high demand and weight have a relatively high impact on to the whole system. Because of the mean demand the fill-rate for these items can be high but still generate many emergency orders. This can happen since the fill-rate will only depend on the proportion between items that can be directly fulfilled from inventory on hand and those that cannot.

8.5 Simulation according to practice at Lantmännen Maskin

The simulation results with the planned lead-time set to four days for all orders from the central warehouse to the retailers are displayed in *Table 26.* The results are very similar to the ones achieved when the correct lead-times are used. A complete list of CO_2-emissions per item for replenishment orders and emergency orders can be found in *Appendix J.*

Table 26. Result from the simulation with the lead-times used in practice displayed as averages per day.

	Fill-rate	Holding Cost	Emergency items, percentage of total	Emergency Items	Total CO_2-emissions
SCP	92.69%	169.67	7.37%	1.90	307.95
MEM	99.62%	139.24	0.39%	0.06	130.46
Diff (%)	7.48%	-17.93%	-94.76%	-96.79%	-57.64%
Mean target fill-rate		98.90%			

The fill-rate increased 7.48% compared to 8.31%, the holding cost is down by 17.93% compared to 18.14%, the emergency items are down by 96.79% compared to 96.77% and the total CO_2 emissions are down by 57.64% compared to 56.99%. Consequently, this means that the performance increases in the same way for both the correct lead-times and the ones used in practice. The only difference that can be seen is that the cost of the total system increases marginally when adding one extra day to the planned lead-time. This is logical and the reason why it does not increase more is because the demand of almost all items is very low. To add extra lead-time to a demand occurring once every second year will not change the reorder point due to the fact that the reorder point is always set to fulfill the service level. The scenario for three days planned lead-time can for instance be that with a reorder point of zero the fill-rate is 80% and with a reorder point of 1 it is above 100%. Then adding one day of lead-time will not change the reorder point for that retailer.

8.6 Comment on the cost of transportation for Lantmännen AB compared other companies

Lantmännen Maskin AB has, as mentioned before, a contract with a land transportation provider which gives them the same price for emergency shipments as for replenishment shipments. This situation is quite peculiar since the cost for the transportation company will differ between these two transportation services. Consequently, when generalizing to other companies assuming that emergency transports by land are "for free" is a faulty assumption. As have been shown, the cost of emergency orders may have a large impact on the total cost of the inventory system which provides an additional incentive to switch from single-echelon to multi-echelon control of an inventory system. To illustrate what the impact may be four different scenarios are analyzed in *Table 29*. *Table 27* and *28* provides information of the scenario set ups.

Table 27. Parameters from the simulation used for the four scenarios.

	Replenishment orders	Emergency orders by air	Emergency orders by truck	Holding Cost (SEK)
SCP	2.93	0.05	0.31	169.25
MEM	3.24	0.01	0.04	138.55
Diff (%)	10.61%	-85.98%	-85.70%	-18.14%

Table 28. The four different scenarios of costs for the different order types.

	Cost per Replenishment order (SEK)	Cost per emergency order by air (SEK)	Costs per emergency order by truck (SEK)
Scenario 1	100	500	500
Scenario 2	100	1000	500
Scenario 3	100	1500	500
Scenario 4	100	2000	1000

Table 29. Results for the four different cost scenarios.

	Total Cost (SEK) Scenario 1	Total Cost (SEK) Scenario 2	Total Cost (SEK) Scenario 3	Total Cost (SEK) Scenario 4
SCP	643.80	669.32	694.83	876.20
MEM	488.70	492.27	495.85	521.71
Diff (%)	-24.09%	-26.45%	-28.64%	-40.46%

In *Table 27* the results from the simulation model which is needed for the cost analysis is displayed. These parameters in combination with the four different cost scenarios in *Table 28* are input to *Table 29*. The four different scenarios in *Table 29* show how the costs are affected if different costs are used for different type of orders. This shows that the cost of the emergency orders can have a significant impact on the total cost of the inventory system. The cost per replenishment order is based on the price of sending a 3 kg domestic package by Posten AB in Sweden. The current price for this (2013-04-26) is 135 SEK (Posten, 2013a).

The different scenarios are examples and only show the potential impact that the cost per emergency orders can have. Companies will have different agreements with the logistics providers available, and hence, these numbers will differ.

Scenario 1 is the most conservative and assumes that the cost of an emergency order is 500 SEK and it does not differ between air and truck. This combination renders an extra savings in the total costs by 6 % from implementing MEM. Scenario 2 and 3 are less conservative and render a total cost savings of 26% and 28% respectively. The last scenario, on the other hand, generates a cost saving of a total 40%. This is more than double then when only the holding costs are taken into consideration. In this scenario the factor 20 was used for emergency orders by air and a factor of 10 for emergency orders by truck in relation to a regular replenishment order. These figures may be a bit high but at least it indicates that there are more costs to reduce than just the holding costs by implementing the MEM model.

The result from this example is that the cost could possibly be down by about 40% instead of 18.1% which is a much larger decrease, and indicates that there are more costs to reduce when switching from SCP to MEM than what first meets the eye.

8.7 Issues related to emergency orders and the analytical models

In this master thesis, the SCP model and the MEM model have been evaluated for the inventory system of Lantmännen, and the impact of emergency shipments on the CO_2-emissions. The two models do not explicitly incorporate emergency orders. This can lead to complications since the emergency orders have a higher priority at the central warehouse than replenishment orders. This will be illustrated with an example, with one central warehouse and N retailers. There is also assumed to be a stock-out at the central warehouse. Because of this stock-out, all replenishment orders will have to wait at the central warehouse until it is refilled from the outside supplier. If the duration of the stock-out at the central warehouse is long there could be shortages at many of the other retailers as well. Then each of these retailers will send emergency orders to the central warehouse. When a replenishment order finally arrives at the central warehouse there could be many incoming emergency orders from these retailers. In the worst case scenario all of the items that just arrived with the replenishment order will be used to fulfill the emergency orders and then there will be a new stock-out.

This scenario threatens to reduce the fill-rate significantly at the retailers since the replenishment orders at the central warehouse will be used to fulfil incoming emergency orders. In this scenario the demand at the retailers will be fulfilled primarily from emergency orders and every emergency order corresponds to a fill-rate reduction.

8.8 Uncertainties in the results

Unfortunately, the standard deviation is quite large in comparison to the mean for some of the performance measures estimated parameters from the simulations. The parameters with high standard deviation to the mean ratios are the amount of emergency orders, emergency items and the emergency transports proportion of the total CO_2-emissions. At first, it was attempted to resolve this by increasing the simulation time until the standard deviation divided by the mean was a very small value, somewhere between 0.5%-1%. The mean is calculated as per day in each simulation block and the standard deviation of this mean value is divided with the number of blocks (i.e. observations). This approach was tested but showed to be infeasible because the number of emergency delivered units for some items is so few that the standard deviation in comparison to the mean was still very big even for extraordinarily long simulation times. As an example the situation when the fill-rate is very close to 1 can be illustrated. In this case during a reasonable amount of simulation blocks, only 1 or a few emergency orders will be generated. Because of this the mean will be very small, and the standard deviation will even though it is small not be significantly smaller than the mean. Extending the simulation time will decrease it but not by much. As an example for one item: by increasing the simulation time with a factor 50 the relation with the standard deviation and the mean for emergency orders was only reduced from 100% to 30%. Hence, from this one see that it is not possible to achieve a low figure on the relation between the standard deviation and the mean for the emergency orders if the fill-rate is very close to 1. Even though this makes the estimated average performance a little more uncertain for some parameters they still show the general implications very well.

Apart from the variability between the different simulation blocks there are other values which will differ. Hence, the results should be used as an indication of the possible savings multi-echelon inventory control can have in comparison to single-echelon control. Examples of uncertain parameter are the loading factors for normal transport where an average for road transport is used and this load utilization may very well vary between different transports to different retailers. A known fact is that the load utilization to the not so densely populated north parts of Sweden is lower than to the south; say for example the capital of Sweden, Stockholm. Therfore using the same load utilizations for all different locations could be questioned. However, there are not any better values available, and therefore this is the only possible way to go. Another uncertain parameter are the CO_2-emissions for the emergency transport by land. For these transports only an average per kg for the whole of Sweden was available. This means that an emergency transport from the central warehouse in Malmö to Umeå (1250km) and to Staffanstorp (15 km) emits the same amount of CO_2 per kg transported goods in this study. This value is also the best value available and consequently could not for the time be improved.

9. Conclusions and discussion

Initially, the conclusions drawn from the results will be demonstrated and reconnected to the purpose of this master thesis. Secondly, a discussion around the results is performed. Especially subjects that can affect the result or be affected by the results are included. The contributions provided from this project are also explained in the discussion. Finally, a brief discussion around suggestions for future research is given.

9.1 Conclusions

The purpose of this master thesis has been to evaluate the environmental and economic benefits that could be attained by switching from single-echelon inventory control to multi-echelon inventory control. The purpose was especially aimed at evaluating the impact of emergency orders. The results show that the MEM model achieves better fulfillment of the target fill-rates; the fill-rate calculated as an average across items and retailers increases by 8%. Using a weighted average based on the average demand per time unit renders a fill-rate improvement of about 24%. Furthermore, the MEM model decreases the holding costs by 18%, decreases the amount of items sent as emergency orders by 97% and reduces the CO_2-emissions by 57% for the test sample of representative products at the case company Lantmännen. Consequently, results indicate that the MEM model is good choice from an environmental perspective and the beauty of it is that the costs are also reduced.

The analysis of the fill-rate showed that the MEM model is much more consistent in achieving target fill-rates and has a maximum positive deviation from the target fill-rate with 6% and a maximum negative deviation of 4%. The performance of the SCP model varies a lot and had a maximum positive deviation from the target fill-rate with 6% and a maximum negative variation of 81%. Consequently, the average fill-rate of the SCP model consists of many very low fill-rates and some high fill-rates which average out to a mean hiding these figures. If the mean fill-rate for the two models is weighted with the mean demand, the weighted mean deviation from the target fill-rate for the MEM model is +0.7% and for the SCP model -24.4%.

The reason that the CO_2-emissions are reduced by as much as 57%, even though the emergency orders are only a little part of the total amount of orders, is that the emergency transports are much less efficient when it comes to CO_2-emissions. Emergency transports are generally also much more expensive and if the costs of the emergency orders are taken into account the cost reduction could be much higher than what the results indicate. The reason is that Lantmännen usually pay their transport provider the same price for regular replenishment and emergency deliveries.

The sensitivity analysis of the emissions per kg goods sent as an emergency order by air showed that the overall results are insensitive to this parameter. The reason is that there are relatively few items shipped by air compared to by land. The sensitivity analysis was further extended to see what the results would be if all emergency orders are sent by air. The results showed substantial reductions of CO_2-emissions in the inventory system and the reduction varied between 78% and 90% for the values 0.3 and 1.5 kg CO_2 per transported kg, respectively.

An interesting result was the fact that the distribution of CO_2-emissions was skewed between different weight intervals. It showed that heavy items have a very large impact on the CO_2-emissions of the whole system. However, the weight alone is not enough but also the mean demand is important. The reason is that when the mean demand is high compared to other items there can be relatively many emergency orders even if the fill-rate is high. This in combination with a heavy item will make this item very important for the CO_2-emissions of the whole inventory system.

During this study two sets of lead-times have been used between the central warehouse and the retailers. This is because Lantmännen adds one extra day as a safety time in the delivery time to the retailers in the south of Sweden (the actual planned lead-time is 3 days). This solution may work well in practice but does not provide entirely correct results. In essence, the difference between the MEM model and the SCP model for this set-up is the same. The only difference that can be identified is that the fill-rate on average is increased by 1% for single-echelon and that the cost is increased infinitesimal for both the methods when using a lead-time of four days to all destinations.

9.2 Discussion

During this project several areas that need further consideration to enable a change of the inventory control system has been identified. The areas discussed in this chapter include the possibility to further decrease the transportation related CO_2-emissions and financial effects caused by the different inventory control systems.

9.2.1 Transportation to and from airports

The transportation to and from the airports has been assumed to be performed by an ordinary distribution truck with normal utilization factor. The reason for this was that the study should not overestimate the CO_2-reduction that could be achieved. However, the transports from the central warehouse to the airport and between the airports and the retailers will have a huge impact, especially if more of the emergency orders are sent by air. This indicates that there are much more CO_2-emissions to reduce than what the results show, and also that it is very important to think through how the transportation actually is performed. It is easy to focus on the air transport but since these transports, and also the regular transportation by land, have high load factors, these transportation modes already have very low CO_2-emissions per kg transported. This is an important point since driving a private car to the airport to pick up an emergency order can undermine all the reduced CO_2-emissions in other parts of the distribution chain. Consequently, the best choice from an environmental perspective is to let a transportation company, which is specialized in making efficient transports, pick-up and deliver the emergency shipments at the airport. This way Lantmännen, and possibly many other companies, can reduce the CO_2-emissions by a large amount.

9.2.2 Suboptimization of the organization due to financial structure

An effect of changing into multi-echelon control instead of single-echelon control is that the stocks tend to be moved towards the customers. This also pushes the stock holding costs to the retailers' stocks instead of the central warehouse's stock which can cause issues. If the retailers' stocks are owned by external parties they might not accept this since they have to invest more capital in their inventories instead of using these money for other investments. However, if so called Vendor Managed Inventories (VMI) are in place (i.e. the supplier controls and owns the stock at its customer) then the step to multi-echelon inventory control is not far. Since the stock is already owned and controlled by the supplier some pieces are already in place to implement multi-echelon inventory control.

Even within organizations there can be structures forcing different business units, such as internally owned retailers, to control their own finances and results. This can cause the business unit doing what is most financially optimal for itself instead of what is the best for the entire organization. In this case they might try to reduce the inventory level and reject the changes leading to more items in stock at the retailers instead of the central warehouse. The result of this is suboptimization of the supply chain. In the current system used at Lantmännen each retailer pays a stock holding cost for the items they keep in stock. This can be an obstacle for Lantmännen if they decide to turn their inventory controlling policy into multi-echelon instead of single-echelon. To enable the change it is important that the costs of the inventory in stock do not completely burden the retailers; instead a change of the financial policy is required.

9.2.3 Emergency orders and supplier discount

Currently, when there is an emergency order arriving at the central warehouse from a retailer and this item is out of stock there, the order will be sent as an emergency order directly to the outside supplier. Normally, the items are purchased from the suppliers based on forecasts to enable the suppliers to plan their production better, and hence, the suppliers are able to give discounts on the products in return. The outside supplier produces many different items but when an emergency order from Lantmännen arrives they will halt their current production to produce the part Lantmännen is demanding. This can be quite costly for the outside supplier and in return Lantmännen are "punished" with a reduced discount on the items ordered as emergency items compared to normal orders. These increased costs are not transferred to the retailers; instead the central warehouse pays them. Consequently, by reducing the need for emergency orders from the retailers, the risk of discount reduction caused by unscheduled ordering is decreased. How this affects the total costs for Lantmännen is outside the scope of this study but nevertheless it should be mentioned since it speak in favor of the multi-echelon inventory control even further.

9.2.4 Contributions

The primary contribution of this master thesis has been to investigate and illustrate the possible environmental and economic benefits that the MEM model can have compared to the SCP model when controlling a multi-echelon inventory system.

Moreover, the methodology of using VBA in Excel to rationalize the data analysis and the simulations in Extend can enable an extension of the number of items studied. By automating the simulation process it is possible to reduce the time needed for simulation of each item, and also to let all simulations run in succession of each other without any need of human interaction between each simulation. This makes it easy to re-run the simulations, if e.g. some changes of input parameters are done. Because this possibility was not known before this project started a lower amount of items were selected to study than what actually could have been feasible. Due to the time constraint of the project it was not possible to add any more items at the point where the methodology was implemented in VBA.

9.2.5 Future research

This case study shows that multi-echelon inventory control offers a large potential to increase the service levels to the end customers and decrease the holding costs and the CO_2-emissions. Purnomo (2011) shows in his study that by incorporating lateral transshipments in a multi-echelon inventory system the service to the customer can increase by 20%. This would be an interesting extension for the multi-echelon model and it could be possible to achieve the same fill-rate levels but with less inventory.

Further, the fact that the emergency orders have higher priority at the central warehouse and threaten to empty the central warehouse of replenishment items would be interesting to investigate. This issue is not directly related to the multi-echelon inventory control and could as easily happen during single-echelon inventory control. The reason that it can happen is because none of the models incorporates the dynamics of the emergency orders. By explicitly incorporating the emergency orders in the control model can further improve its accuracy, and hence, the costs, fill-rates and emissions could be affected in a positive way.

10. References

10.1 Books

AXSÄTER, S., 2006. *Invetory Control.* Second Edition edn. New York, NY: Springer.

BJÖRKLUND, M. and PAULSSON, U., 2003. *Seminarieboken – att skriva, presentera och opponera.* Lund: Studentlitteratur.

BRYMAN, A. and BELL, E., 2011. *Business Research Methods.* 3rd Edition edn. New York: Oxford University Press, Inc.

DENSCOMBE, M., 2011. *Forskningshandboken – för småskaliga forskningsprojekt inom samhällsvetenskaperna.* Second Edition edn. Lund: Studentlittertur AB.

HILLIER, F.S. and LIEBERMAN, G.J., 2001. *Introduction to operations research.* 7th Edition. New York: The McGraw-Hill Companies, Inc.

HÖST, M., REGNELL, B. and RUNESON, P., 2006. *Att genomföra ett examensarbete.* Lund: Studentlitteratur AB.

KARLSSON, C., 2009. *Researching Operations Research.* Oxon: Taylor & Francis.

LAGUNA, M. and MARKLUND, J., 2004. *Business Process Modeling, Simulation and Design.* Second Edition. New Jersey: Pearson Prentice Hall.

LAW, A.M. and KELTON, D.W., 2000. *Simulation Modeling and Analysis.* Georgia: The McGraw-Hill Companies, Inc.

MUCKSTADT, J.A., 2005. *Analysis and Algorithms for Service Parts Supply Chains.* New York: Springer.

ROSENGREN, K.E. and ARVIDSON, P., 2002. *Sociologisk metodik.* Fifth edition. Malmö: Liber AB.

ZIPKIN, P.H., 2000. *Foundations of Inventory Management.* USA: McGraw-Hill/Irwin.

10.2 Journal Articles

ADELSON, R.M., 1966. *Compound Poisson Distributions*. *Operational Research Society,* **17**(1), pp. 73.

AGENCY, E.E., 2012-last update, GHG trends and projections in the EU-27. [Homepage of European Environment Agency], [Online]. Available: http://www.eea.europa.eu/publications/ghg-trends-and-projections-2012 [01/14, 2013].

ALFREDSSON , P., 1997. *Optimization of multi-echelon repairable item inventory systems with simultaneous location of repair facilities*. *European Journal of Operational Research,* **99**, pp. 584-595.

ANDERSSON, J., AXSÄTER, S. and AND MARKLUND, J., 1998. *Decentralized multi-echelon inventory control*. *Production and Operations Management,* **7**, pp. 370-386.

AXSÄTER, S., 2005. *A simple decision rule for decentralized two-echelon inventory control*. *International Journal of Production Economics,* **93**, pp. 53-59.

AXSÄTER, S., 2000. *Exact Analysis of Continuous Review (R, Q) Policies in Two-Echelon Inventory Systems with Compound Poisson Demand*. *Operations Research,* **48**(5), pp. 686-696.

AXSÄTER, S., 1993. *Exact and Approximate Evaluation of Batch-Ordering Policies for Two-Level Inventory Systems*. *Operations Research,* **41**(4), pp. 777-785.

AXSÄTER, S., FORSBERG, R. and ZHANG, W., 1994. *Approximating general multi-echelon inventory systems by Poisson models*. *International Journal of Production Economics,* **35**, pp. 201-206.

BERLING, P. and MARKLUND, J., 2013. *A model for heuristic coordination of real life distribution inventory systems with lumpy demand*. *European Journal of Operational Research,* forthcoming.

BERLING, P. and MARKLUND, J., 2012. *Multi-Echelon Inventory Control – A Normal Demand Model for Implementation in Practice*. Working paper, Lund University.

BERLING, P. and MARKLUND, J., 2006. *Heuristic Coordination of Decentralized Inventory Systems Using Induced Backorder Costs*. *Production & Operations Management*, **15**(2), pp. 294-310.

COHEN, M., KLEINDORFER, P., LEE, H. and PYKE, D., 1992. *Multi-item service constrained (s, S) Policies for spare parts logistics systems*. *Naval Research Logistics*, **39**, pp. 561-577.

CRISTEA, A., HUMMELS, D., PUZZELLO, L. and AVETISYAN, M., 2013. *Trade and the greenhouse gas emissions from international freight transport*. *Journal of Environmental Economics and Management*, **65**, pp. 153-173.

GALLEGO, G., ÖZER, Ö., ZIPKIN, P., 2007. *Bounds, Heuristics, and Approximations for Distribution Systems. Operations Research*, **55**(3), pp. 503-517.

GÜMÜS, T. and GÜNERI, F., 2007. *Multi-echelon inventory management in supply chains with uncertain demand and lead times: literature review from an operational research perspective*. *Journal of Engineering Manufacture*, **221**, pp. 1553-1570.

HAUSCHILD, M.Z., LAURENT, A. and OLSEN, S.I., 2012. Limitations of Carbon Footprint as Indicator of Environmental Sustainability. *Environmental science & technology*, **46**(7), pp. 4100-4108.

HAUSMAN, W.H. and ERKIP, N.K., 1994. *Multi-echelon vs. Single-echelon Inventory Control Policies for Low-demand Items Management Science*, **40**(5), pp. 597-602.

KENNEDYA, W.J., PATTERSON, J.W. and FREDENDALL, L.D., 2002. *An overview of recent literature on spare parts inventories. International Journal of Production Economics*, **76**, pp. 201-215.

NETWORK FOR TRANSPORT AND ENVIRONMENT, 2011. *Environmental data for international cargo and passenger air transport. The* Network for Transport and Environment.

NETWORK FOR TRANSPORT AND ENVIRONMENT, 2010. E*nvironmental data for international road transport Europe*. 4. The Network for Transport and Environment.

PURNOMO, A., 2011. *Multi-echelon Inventory Model for Repairable Items Emergency with Lateral Transshipments In Retail Supply Chain*. *Australian Journal of Basic and Applied Sciences*, **5**(3), pp. 462-474.

SAMIMI, A. and ZARINABADI, S., 2011. *Reduction of Greenhouse Gases Emission and Effect on Environment Australian Journal of Basic and Applied Sciences*, **5**(12), pp. 752-756.

SHERBROOKE, C.C., 1968. *METRIC: a multi-echelon technique for recoverable item control*. *Operations Research*, **16**, pp. 122-141.

10.3 Master thesis

CALLENÅS, O., LINDÉN, C., 2010. *Analysis of a coordinated multi-echelon inventory control system: -A case study on its performance compared to the current inventory control system at Syncron*, Department of Industrial management & Logistics production management.

RÄNTFORS, O., 2012. *Benefits of Multi-Echelon Inventory Control*, Division of Production Management, Department of Industrial Management and Logistics.

RASMUSSON, S., SUNESSON, B., 2010. *Coordinated inventory control: - A case study on its performance compared to the current system at IKEA*, Department of Industrial Management & Logistics, Production Management.

10.4 Personal Communication

POSTEN, 2013b. *Mail correspondence.*

HERSNER, C., 2013a. *Interview.*

HERSNER, C., 2013b. *Mail correspondence.*

JETPAK, 2013. *Mail correspondence.*

10.5 Web Pages

EUROPEAN ENVIRONMENT AGENCY, 2012-last update, *GHG trends and projections in the EU-27*. [Homepage of European Environment Agency], [Online]. Available: http://www.eea.europa.eu/publications/ghg-trends-and-projections-2012 [01/14, 2013].

LANTMÄNNEN MASKIN AB, 2013a-last update, *Företagsfakta Lantmännen Maskin* [Homepage of Lantmännen Maskin AB], [Online]. Available: http://www.lantmannenmaskin.se/sv/Om-oss/Foretagsfakta/ [02/14, 2013].

LANTMÄNNEN MASKIN AB, , *Miljö- och kvalitetspolicy* [Homepage of Lantmännen Maskin AB], [Online]. Available: http://www.lantmannenmaskin.se/sv/Om-oss/Miljo-och-kvalitet/Miljo--och-kvalitetspolicy/ [02/14, 2013].

NATIONALENCYKLOPEDIN, 2013-last update, Maximum likelihood-metoden [Homepage of Nationalencyklopedin], [Online]. Available: http://www.ne.se/maximum-likelihood-metoden [01/16, 2013].

NATIONALENCYKLOPEDIN, , *Kyotoprotokollet* [Homepage of Nationalencyklopedin], [Online]. Available: http://www.ne.se.ludwig.lub.lu.se/lang/kyotoprotokollet [01/14, 2013].

NATIONALENCYKLOPEDIN, , Kyotoprotokollet [Homepage of Nationalencyklopedin], [Online]. Available: http://www.ne.se.ludwig.lub.lu.se/lang/kyotoprotokollet [01/14, 2013].

POSTEN, 2013a, *Skicka Direkt* [Homepage of Posten AB], [Online]. Available: http://skicka.posten.se/service/skicka/Pages/serviceSettings.aspx?ServiceKey=Postpaket_inrikes [04/26, 2013].

SYNCRON, 2013-last update, Manage your supply chain - Easily [Homepage of Syncron], [Online]. Available: http://www.syncron.com/en/About-Syncron/supply-chain-solutions/ [01/16, 2013].

SYNCRON, 2013-last update, Supply Chain Management Software and Pricing Solutions [Homepage of Syncron], [Online]. Available: http://www.syncron.com/en/ [01/16, 2013].

VOLKSWAGEN TRANSPORTBILAR, 2013-last update, *Nya Transporter* [Homepage of Volkswagen Transportbilar 2013], [Online]. Available: http://www.volkswagen-transportbilar.se/content/medialib/vwd4/vwn_se/modeller/transporter/pdf/transporter_pdf_2011_utg_3/_jcr_content/renditions/rendition.file/2011_transporter_se.pdf [04/27, 2013].

Appendix A : Delimitations in the data extraction

Delimitate to:

- **Time Period January 2011 –December 2012**
- **The Swedish market**
  - ➢ Exclude article transactions outside the Swedish market (e.g. Norway and Denmark with currencies NOK and DKK), since most facilities there are owned by external parties.

- **Articles demanded at least once during the time period**

Exclude the following:

- **The facility in Kalmar**.
  - ➢ Kalmar Lantmän since this facility is owned by an external party.
- **Suppliers according to Excel file "Året 2012_2011_Butiks-leverantörer".**
  - ➢ These suppliers only deliver straight to the shops, and hence, will be excluded from the analysis.
- **Supplier 001 and Supplier 495**.
  - ➢ These suppliers deliver straight to the facilities without passing the CW

File specification from Lantmännen

File specification for data file 1 consisting of demand transactions per dayfor the time interval 2011/01/01-2012/12/31.

Column name	Description
Master Item Code	Unique Id of an item
Warehouse Code	Unique Id of a warehouse
Warehouse name	The city the warehouse is located in
Demand quantity	The size of the demand in units
Delivered quantity	The amount actually delivered in units
Date of demand	The date the demand occurred

The next data file, data file 2 consists the aggregated demand per month for the same time interval as data file 1.

Column name	Description
Master Item Code	Unique Id of an item
Warehouse code	Unique Id of a warehouse
Demand quantity	The size of the demand in units (aggregated per month)
Demand quantity	The size of the demand in units (aggregated per month) excluding articles which have been replaced
Date of demand	The month the demand occurred

Data file 3 contains specific information of each item and warehouse combination in the system.

Column name	Description
Master Item Code	Unique Id of an item
Warehouse Code	Unique Id of a warehouse
Warehouse name	The city the warehouse is located in
Description	Description of each item
Current stock	The current level in units held in stock at each retailer
Unit cost	Cost of each item
Unit cost currency	The currency used for the cost
Weight	The weight
Weight unit of measure	Unit of measure used for the weight
Volume	The volume of each item
Volume unit of measure	Unit of measure used for the volume
Lead Time	The time in days between the occasion an order is sent from the retailer to the central warehouse until it arrives at that same retailer.
Mean per month	This is not the true mean but a forecast calculated by the system
Standard deviation per month	This is not the true standard deviation but a forecast calculated by the system forecast calculated by the system
Order quantity	The order quantity which the retailer has to order from the central warehouse
Target service level	The target service level as decided by the system
Reorder point	The is inventory level including outstanding orders, which will trigger a replenishment order
Actual service level	The actual service level during the time interval specified
Supplier code	Unique Id of a supplier

Appendix B: Interview with case company

Interview date: 6^{th} of February 2013

Interviewers: Sven Nilsson and Lina Ottosson

Interviewee: Claes Hersner& Klas Merkel

Duration: 3 hours

Introduction

- *Can you tell us about Lantmännen and this department?*

The turn-over in Sweden is about 3.5 billion and 4.5 billion when Denmark and Norway is included as well. SWECON is in the same division and has 20 facilities in Sweden. It is a sister (associated) company with the same divisional manager, but different CEOs.

In the Central Warehouse there are about 50,000 active articles. Every day there are about 150-160 delivery points (total of 200 depots). Each year there is 500,000 orde rlines of spare parts sent from the CW out to the retailers. Some parts are very low frequent and only moved every 3-4 month.At the moment there are about 240 suppliers on the purchasing side of the CW. Some of the "bigger" often require pre-season orders to give a good discount etc. because they want to be able to plan their production.

At least three sales (physical withdrawals) are required each year for an article to qualify to be in stock at the CW. An article without any stock movement in 18 months will be returned to the CW since it increases the possibility to be able to send it to more necessitous markets. In 2011 about 30000 articles (not unique part no) were included in this return handling process from local facilities.

The most significant customers are the workshops (repair machines) and not directly the farmers. (About 50%.) These resources can be very expensive if the stagnate and the customers cannot be debited. However, the workshops should plan the work, but sometimes rush orders are required, e.g. if there is a machine supposed to be repaired and then they realize that something else is wrong than first expected. Required spare parts might not be in stock then and a rush order is needed to be triggered to avoid (too high costs) further problems for the owner of the machine.

The cooperation with Syncron started in 2006.There is no connection between Syncron and the machines; their system only handles spare parts.

Brochures werealso received and “Green Annual Report”will be sent through e-mail.

General fact about the warehouse

- *Describe your inventory system in the matter of:*
    - *How is the inventory level reported (continuously/daily/weekly etc.)*
        - *Or a mix of both?*

        The system checks the inventory levels continuously every day. Some products, like harvesters, are only checked during some parts of the year when it is season. Every night there is information about history sent from the ERP-system. Once a week the CW figures stock for order Level etc, is updated with the information from the system. Afterwards recalculations are done and new suggestions for orders to suppliers are made of the system.

- ➢ *Transportation times between retailers and the central warehouse? And from supplier to the central warehouse (CW)? Regular and emergency transports?*

  The lead-time is 3-4 days for the Swedish facilities and 4-5 days outside Sweden. (Earlier it was 30-35 days). The order quantity was reduced with the decreased lead-time. From the external suppliers to the CW it is 20-35 days (information about this can be found in Syncron's system), and the lead-times for all articles from the same supplier are the same.

- ➢ *How frequently are replenishment orders sent to the retailers? Every time there is a check of inventory level or are orders consolidated and sent at a certain time, e.g. once a week/day?*

  Deliveries are made to each retailer on a daily basis.

- *Is there direct demand at the central warehouse? i.e. an customers go directly and order from the CW with no regional warehouse in between?*

  The CW does not sell directly to the customers.

- *According to our data analysis 50 % of all articles are only demanded from 1 retailer, can this be correct? (Explain)*

  Intuitively no but if this information is inSyncron's system this is correct. To be on the safe side we will check this up.

- *Who is the owner of the retailer's stock points? E.g. "Franchising"?*

In Denmark and Norway the retailers' dealer stock's points value are owned by themselves (except for some dealers in Norway who belongs to Lantmännen Maskin).

In Sweden all facilities are internally owned (Except for Kalmar Lantmän).

- *What is the lead-time from the central warehouse?*

  Within the warehouse: Refill- 1 day, pick-up day 2 and delivery day 3 or 4. Emergency orders reported before 4 pm will be delivered next day (7 am). Normally: Day 1 – Order made, day 2- outgoing delivery, day 3- transportation, day 4- Incoming delivery
- *How long is the transportation time from the central warehouse to the different retailers?*

  This information is available in Syncron's system.

Environmental policies

- *Do you have any certain environmental policies at Lantmännen?*

  Not concerning emergency orders but read about general environmental policies in the "Green Annual Report".
- *How do you measure your environmental impact?*

  We use CO_2 as measurement.
- *Do you have any data on average CO_2–emissions per emergency transport and retailer?*

  We will gather this information for you from the transportation companies HIT (regular transport) and Jetpak (emergency transports).

- *Multi-echelon models have a tendency to push stock from the central warehouse out to the regional warehouses. Is this going to* *be a practical problem for your organization? If so what could be done to reduce this?(mathematically in the model (e.g. some restriction like a ration between stock on the central warehouse and the regional warehouses))*

This is not a problem for the retailers which are internally owned.

Emergency orders

- *Mode of transportation for regular transports and emergency transports?*
  - *Decision rule for this*

  Regular transports are by truck, emergency transports vary in mode of transportation. The firm Jetpak handles the emergency shipments and ultimately decides which mode to choose to be able to deliver the order in time. Essentially, this means transportation by air north of Uppsala, Örebro, Karlstad and land transport for the rest of Sweden.

- *Decision rule when to send emergency transport and by which mode of transportation to select for each transport? Where and when is the decision made?*
- *How many emergency orders are there per retailer compared to regular orders?*

  Information about this will be sent. (The percentage rate can then be calculated)
- *How do the emergency orders affect the FCFS (First Come First Serve) rule we assume are used at the central warehouse?*

  They are first priority (first in line). The drawback is that customers ordering correctly and responsively in an environmental way will get their orders processed after the emergency orders.

- *Where are the decisions about emergency orders made?*
    - *Any difference between central guidelines and practice?*

  The final decision lies at the customer because it is the customer who will pay for the extra transportation cost. The salesman will in compliance with the central guidelines have a conversation on how important the part is for the customer which aims at minimizing the emergency orders as much as possible. The only difference noticeable is that there are different percentage rates of emergency orders compared to regular orders at different retailers.

- *Who pays for the emergency orders? (extra transportation costs)*

  The customer pays for the emergency orders. The unit cost for the facilities within the organization is the same; however, if there also is a stock out at the CW this means that they need to send an emergency order to their supplier. If the CW sends an emergency order to the outside supplier the items bought via this order will cost more than a regular order but this cost is not transferred to the retailer ordering the emergency order.

  For Denmark, Norway and Kalmar there are different percentage rates for different lead-times/transportation modes etc. to make them choose the right option.
- *If the item requested for an emergency order is out of stock at the central warehouse, is an order placed with the outside supplier? Which mode is used if this is the case?*

  Yes, the fastest mode of transportation possible. The CW trusts that the retailer's decision about emergency order is correct and will not second guess it.

Needed information

- *To be able to calculate costs as accurately as possible we would like the following information:*
    - *Internally calculated holding costs? How do you calculate it? Any percentage rate?*

      8% + approximately 5% to run the stock administration system (for depreciations etc).The exact holding cost will be calculated exactly by Lantmännen for all the items selected for the simulation study.

    - *The cost of emergency transports and regular transports per retailer?*

      The same as for regular transport, air is more expensive though.

    - *Batch quantities at the warehouses (Q)?*

    They are available in Syncron's system (calculated once a week).

Delimitations agreed upon on during the interview

- Only spare parts will be studied.
- The focus should be on the retailers owned internally by Lantmännen, this excludes retailers in Denmark, Norway and in Kalmar, Sweden.
- Only items supplied to the retailers via the CW should be studied, this excludes items from Swecon.
- The articles which are a part of the shop range are excluded from the data set.

Appendix C

Original system parameters	**Normalized system parameters**
Q_i	$Q_{i,n}$=100 $Q_i/(\mu_i\ l_i)$
Q_0	$Q_{0,}n$=Q_0
h_i	$h_{i,n}$=1
h_0	$h_{0,n}$= h_0/h_i
p_i	$p_{i,n}$= p_i/h_i
L_0	$L_{0,n}$= L_0
l_i	$l_{i,n}$=1
μ_i	$\mu_{i,n}$=100
σ_i	$\sigma_{i,n}$=100 $\sigma_i/\sqrt{u_i}$
β_i= $\beta_{i,n}h_i$	$\beta_{i,n}$

(Source: Berling and Marklund (2006))

Appendix D: The different strata

	Lower	Upper	0/1	Lower	Upper	Lower	Upper	Lower	Upper
Strata	Coefficient of variation		Air	Weight		Unit cost		Mean demand per year	
1	0	1	1	0	25	0	100	0	5
2	0	1	1	0	25	0	100	5	20000
3	0	1	1	0	25	100	500	0	5
4	0	1	1	0	25	100	500	5	20000
5	0	1	1	0	25	500	10000	0	5
6	0	1	1	0	25	500	10000	5	20000
7	0	1	1	25	500	0	100	0	5
8	0	1	1	25	500	0	100	5	20000
9	0	1	1	25	500	100	500	0	5
10	0	1	1	25	500	100	500	5	20000
11	0	1	1	25	500	500	10000	0	5
12	0	1	1	25	500	500	10000	5	20000
13	0	1	0	0	25	0	100	0	5
14	0	1	0	0	25	0	100	5	20000
15	0	1	0	0	25	100	500	0	5
16	0	1	0	0	25	100	500	5	20000
17	0	1	0	0	25	500	10000	0	5
18	0	1	0	0	25	500	10000	5	20000
19	0	1	0	25	500	0	100	0	5
20	0	1	0	25	500	0	100	5	20000
21	0	1	0	25	500	100	500	0	5
22	0	1	0	25	500	100	500	5	20000
23	0	1	0	25	500	500	10000	0	5
24	0	1	0	25	500	500	10000	5	20000
25	1	5	1	0	25	0	100	0	5
26	1	5	1	0	25	0	100	5	20000
27	1	5	1	0	25	100	500	0	5
28	1	5	1	0	25	100	500	5	20000
29	1	5	1	0	25	500	10000	0	5
30	1	5	1	0	25	500	10000	5	20000
31	1	5	1	25	500	0	100	0	5
32	1	5	1	25	500	0	100	5	20000
33	1	5	1	25	500	100	500	0	5
34	1	5	1	25	500	100	500	5	20000
35	1	5	1	25	500	500	10000	0	5
36	1	5	1	25	500	500	10000	5	20000
37	1	5	0	0	25	0	100	0	5
38	1	5	0	0	25	0	100	5	20000
39	1	5	0	0	25	100	500	0	5
40	1	5	0	0	25	100	500	5	20000
41	1	5	0	0	25	500	10000	0	5
42	1	5	0	0	25	500	10000	5	20000
43	1	5	0	25	500	0	100	0	5
44	1	5	0	25	500	0	100	5	20000
45	1	5	0	25	500	100	500	0	5
46	1	5	0	25	500	100	500	5	20000
47	1	5	0	25	500	500	10000	0	5
48	1	5	0	25	500	500	10000	5	20000

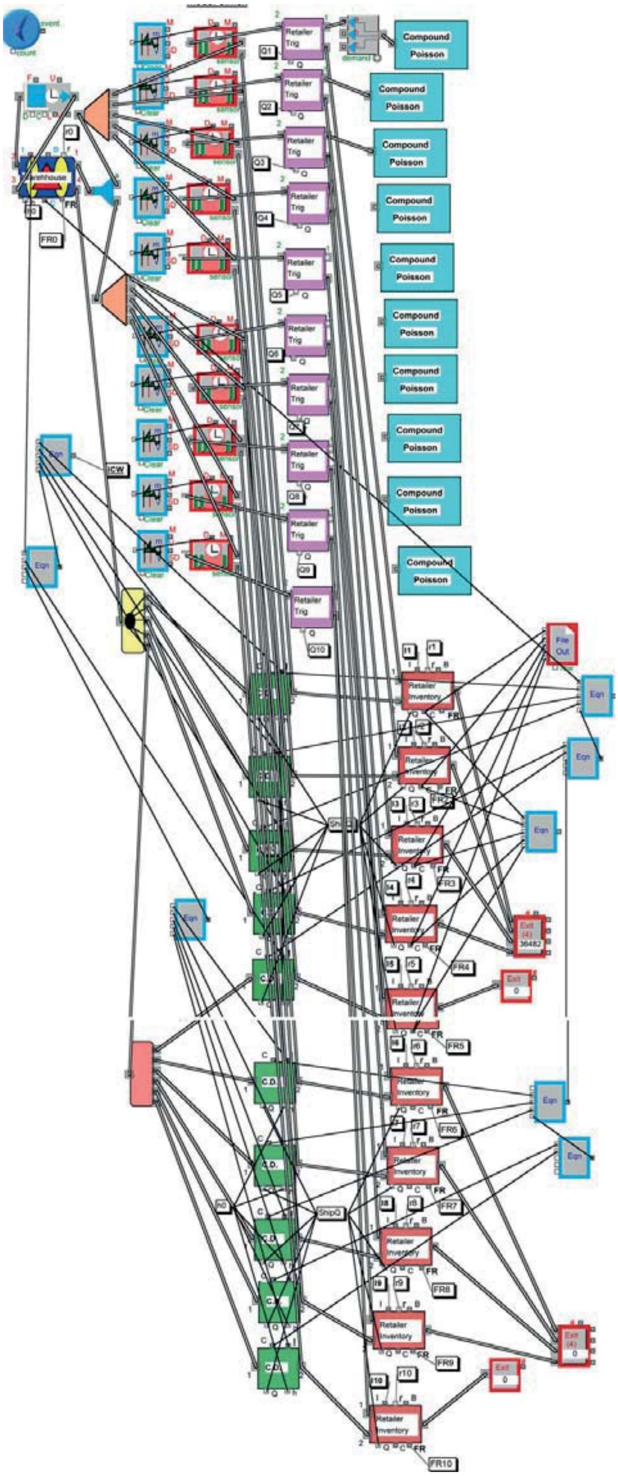
Appendix E: All the items and their strata

ITEM_NBR	Coefficient of variation	Air	Weight	Unit cost	Mean demand per year	Strata
1	4.14	0	0.07	29.45	2.00	37
2	3.65	1	0.031	165.75	24.50	28
3	4.70	0	0.044	187.12	7.50	40
4	4.90	0	0.168	105.01	3.00	39
5	3.55	0	27.115	126.31	40.00	46
6	4.14	0	0.149	131.26	6.00	40
7	4.57	1	0.01	1.67	12.00	26
8	3.99	1	0.013	13.86	29.00	26
9	4.90	0	0.008	0.11	2.00	37
10	4.90	0	0.042	2.49	2.00	37
11	4.31	1	0.083	5.21	39.00	26
12	4.90	0	0.003	0.9	11.50	38
13	4.56	0	0.037	47.72	4.50	37
14	2.95	1	0.037	2.44	1377.50	26
15	4.14	0	0.037	3.25	8.00	38
16	3.27	1	0.478	95.36	53.00	26
17	4.90	0	0.046	36.55	1.50	37
18	3.48	0	0.128	32.16	12.50	38
19	3.61	0	0.079	8.77	4.00	37
20	3.57	0	0.002	0.43	52.00	38
21	3.18	0	30	1705.51	6.00	48
22	4.23	0	0.289	98.59	5.50	38
23	2.48	1	0.08	13.15	407.50	26
24	2.98	0	0.016	31.72	2.50	37
25	4.90	1	0.047	3.95	3.50	25
26	3.68	0	1.034	219.97	14.50	40
27	3.99	0	0.002	3.29	20.00	38
28	4.23	0	0.091	28.72	4.50	37
29	2.39	1	1.518	277	75.00	28
30	3.39	0	0.302	92.46	1.00	37
31	4.68	0	1.4	52.24	21.00	38
32	4.90	0	0.013	19.205	4.50	37
33	4.90	0	0.007	25.84	0.50	37
34	4.68	0	1.188	37.02	7.00	38
35	4.40	0	0.012	5.7	3.00	37
36	4.90	1	3.66	625.94	4.50	29
37	4.21	0	0.306	2661.84	9.50	42
38	4.08	0	0.101	30.91	44.00	38
39	3.89	0	0.15	753.86	1.50	41
40	4.90	0	1.3	202.53	3.50	39
41	2.90	0	0.5	71.75	162.50	38
42	2.70	0	25	426.87	1.50	45

ITEM_NBR	Coefficient of variation	Air	Weight	Unit cost	Mean demand per year	Strata
43	4.90	0	0.009	4.72	1.00	37
44	2.65	0	0.5	64.44	3.00	37
45	4.41	1	0.03	76.12	15.00	26
46	3.88	1	0.011	72.38	14.00	26
47	4.73	1	0.03	168.46	9.00	28
48	4.29	1	0.04	153.81	2.50	27
49	3.39	0	100	3076.58	1.00	47
50	4.27	1	0.18	1079.61	16.00	30
51	3.89	0	0.01	20.11	10.00	38
52	4.50	1	0.02	13.22	7.50	26
53	3.04	1	0.11	84.3943	66.00	26
54	4.04	1	0.12	128.91	25.50	28
55	4.90	0	0.05	300.77	1.00	39
56	3.83	1	0.06	96.02	4.50	25
57	4.90	0	0.077	70.14	0.50	37
58	4.90	0	0.24	220.22	4.50	39
59	4.07	0	0.01	53.69	5.50	38
60	4.11	0	0.003	74.49	10.50	38
61	2.87	1	0.3	1062.55	53.00	30
62	3.61	1	5.8	823.33	19.00	30
63	4.90	1	0.01	45.73	4.00	25
64	3.31	1	5.24	1577.77	60.50	30
65	4.23	0	6.14	5765.04	4.50	41
66	4.32	1	1	29.66	13.50	26
67	4.60	0	0.05	34.68	5.00	38
68	2.92	0	0.04	183.6	12.00	40
69	2.09	1	0.54	46.98	1344.50	26
70	1.87	1	0.05	28.69	795.00	26
71	3.02	1	0.5	178.71	39.00	28
72	3.97	1	1	157.48	9.00	28
73	4.00	1	0.52	313.27	7.00	28
74	3.37	1	0.085	62.85	106.50	26
75	4.90	1	0.09	66.42	1.00	25
76	3.36	0	0.007	26.83	9.00	38
77	4.40	1	0.202	210.12	3.00	27
78	4.71	1	0.005	2.49	10.50	26
79	4.90	1	0.021	32.6344	5.50	26
80	1.15	1	0.74	83.117	536.00	26
81	4.03	0	0.329	256.58	8.00	40
82	4.60	1	1.595	280.73	5.00	28
83	2.86	0	0.195	531.19	17.00	42
84	3.59	0	0.568	139.12	1.50	39
85	4.90	1	0.026	16.85	11.00	26

ITEM_NBR	Coefficient of variation	Air	Weight	Unit cost	Mean demand per year	Strata
86	4.40	0	0.104	119.3	3.00	39
87	4.04	1	0.004	15	22.50	26
88	3.52	1	0.542	69.6	7.00	26
89	3.06	1	0.002	5.17	74.50	26
90	4.90	0	1.23	17.85	0.50	37
91	3.27	1	0.028	54.44	37.00	26
92	3.89	0	0.26	92.45	1.50	37
93	1.00	1	0.4	95.5743	710.00	2
94	3.46	1	0.14	105.084	189.50	28
95	3.69	0	0.05	14.97	106.50	38
96	0.96	1	0.461	370.82	715.50	4
97	3.80	0	0.01	6.11	6.00	38
98	3.46	1	0.18	257.48	42.50	28
99	3.85	1	0.01	0.72	84.00	26
100	4.19	1	0.01	11.92	12.00	26
101	4.30	1	0.001	9.14	8.00	26
102	4.35	1	0.199	69.07	5.50	26
103	4.23	1	0.33	120.51	17.50	28
104	3.70	1	0.23	126.38	36.50	28
105	3.92	1	0.01	59.09	10.00	26
106	4.52	0	0.01	12.4	4.00	37

Appendix F: Simulation model



Appendix G: Excel Model

Input data to the Excel model

The multi-echelon inventory control model developed by Berling and Marklund (2012;2013), denoted MEM in this master thesis, is implemented in VBA in Excel. This model assumes either a compound Poisson demand at the retailers or a normal demand depending on what the user chooses.

To be able to use the Excel model the following input data is required:

- Date and size of all demands occurring at the retailers and the central warehouse per item during the time period 2011-01-01 to 2012-12-31.
- Order quantity at the retailers and the central warehouse
- Lead time between the central warehouse and the retailers as well as the lead time between the outside supplier and the central warehouse
- Target fill rates per item and retailer
- Unit cost for each item at each retailer and the central warehouse

Mean and standard deviation for the selected 106 items was calculated per day since the simulations will be performed with the unit of time set to days.

As was concluded in the data analysis, see *chapter 5*, all demands at the retailers for all items are modeled as compound Poisson demand with empirical compounding distributions. Hence, the Excel model needs the probabilities that different demand sizes occur for the compounding distribution as input for each item. Lambda, i.e. the arrival intensity, of the customer demand is however not needed since the model uses the mean and the standard deviation combined with the probabilities for different demand sizes to fit a lambda.

Input data such as the order quantities, the reorder points and the target fill-rates were calculated with the single-echelon method used at Syncron. The lead-times were determined by Lantmännen and the holding costs for each item were calculated with an interest rate of 13.5%.

Settings made in the Excel model

When all the input data was inserted into the Excel model additionally 10 different settings needed to be filled in for each items in the interface of the Excel model. The settings are as follows:

- Leadtime_choice
- No. of Retailers (N)
- CW_demand
- Ret_demand
- Choice
- Cost_FR_opt
- Local_search
- Undershoot comp.
- Compounding dist
- Ret_demand choices
    - Normal
    - NegBin

- o Compound Poisson-Geometric
- o Poisson
- o Compound Poisson-Empirical

- CW_demand choices
  - o D_warehouse
  - o D_warehouse_new
  - o D_warehouse_N_approx
  - o D_warehouse_Gamma
  - o D_warehouse_NegBin

Leadtime_choice

The leadtime_choice parameters five different options to approximate the leadtime from the central warehouse to the retailers:

- **Little** - use the METRIC approximation with Little's formula to approximate the lead_time.
- **Exp delay** - the delay is approximated with the exponential distribution.
- **Normal Delay** - the delay is approximated with the normal distribution according to the approach in Axsäter (2005).

The Leadtime_choice made in this Master Thesis was Little for all items, this is because this method have proven to be the most accurate in previous research.

No. of Retailers (N)

This setting is as straight forward as it sounds, that is the number of retailers this particular item has.

CW_demand

This option decides which statistical distribution the model will use to approximate the demand from the retailers to the central warehouse. There are four choices that can be made:

- **D_warehouse** - calculates the exact demand at the central warehouse, this option can lead to long calculation times and possibly timeout of the VBA macro.
- **D_warehouse_new** - The same as above but this method is a little bit faster.
- **D_warehouse_N_approx** - The normal approximation is fast to calculate but if the standard deviation is not significantly smaller than the mean than there are large probabilities for negative demand. (Chapter 4.2.2)
- **D_warehouse_Gamma** - The Gamma distribution should be used if the standard deviation is smaller than the mean but not significantly smaller. (Chapter 4.2.2)
- **D_warehouse_NegBin** - The Negative binomial is used if the mean is smaller or equal to the mean. (Chapter 4.2.2)

Since the mean in this study always was smaller than the standard deviation D_warehouse_NegBin was used for all items.

Ret_demand

The Ret_demand is the demand distribution between the end customer and the retailer which can be approximated in five different ways:

- **Normal distribution**
- **Negative Binomial distribution**
- **Compound Poisson-Geometric distribution**

- **Poisson distribution**
- **Compound Poisson-Empirical distribution**

When the normal approximation is not suitable the NegBin option, Negative Binomial, can be used since it does not have any probabilities for negative demand, and hence, will work when the standard deviation is larger than the mean. The last three options consists of three different types of Poisson demand, whereas the compound Poisson demand is the demand distribution which is the best fit to the real customer demand. For the customer demand there are two different compounding distributions to choose from; the geometric distribution and the empirical distribution. The empirical distribution is used when the customer demand quantity is hard to fit to the geometric distribution either because there are not enough data on the demand or if the demand quantity varies too much. If the customer is only allowed to order one single quantity the simple Poisson distribution can be used and are in these cases as accurate as the compound Poisson distribution but much less computationally demanding.

The data analysis, see *Chapter 5*, showed that it was hard to find any item where all the retailers had a compounding distribution that could be determined. In most of the cases this was due to the low demand which generated too small data samples to be able to fit any distribution to it. Hence, the only option available was to choose the Compound Poisson-Empirical for all items.

Choice

This setting determines how the induced backorder cost is calculated. The two options to choose between are to use tabulated values or let excel calculate the induced backorder cost for each specific case.

The tabulated version was used in this Master Thesis since it had shown the best results in previous research.

Cost_FR_opt

The Cost_FR-opt option determines if the model should optimize on cost or service level.

Since Lantmännen has fill-rates constraints they want to achieve the setting which optimizes the cost under a fill-rate constraint was used in this study.

Undershoot comp.

This setting determines which type of undershoot compensation the excel model should use, the available choices are:

- **No adjustment** - Undershoot adjustment turned off
- **Calculate the reorder point (R) so that service level are fulfilled based on the distribution of the inventory position when an order is placed which is R-undershoot**
- **Adjust the mean lead-time demand with the expected customer order size**
- **Adjust the mean lead-time demand with the expected undershoot**
- **Adjust the variance of the lead-time demand with the variance of the customer order size**
- **Adjust the variance of the lead-time demand with the variance of the undershoot**

In this Master Thesis "Calculate the reorder point (R) so that service-level are fulfilled based on the distribution of the inventory position when an order is placed which is R-undershoot" was chosen for the undershoot compensation.

Compounding dist

Compounding dist lets the user define which compounding distribution is used. These five choices are available:

- **Empirical use "output"-sheet to insert distribution** - An empirical compounding distribution is used, the data for the compounding distribution is pasted in sheet "output".
- **Geometric compounding - fit expected value and variance of leadtime demand** - A geometric compounding distribution is used and the VBA-macro uses the mean and variance in the sheet to calculate the corresponding beta.
- **Geometric compounding - given beta below** - Same as above but the beta is already available, and hence, the beta is used as input to the model to save some calculations for the VBA-macro.
- **Logaritmic compounding - fit expected value and variance of leadtime demand** - A logaritmic compounding distribution is used and the VBA-macro uses the mean and variance in the sheet to calculate the corresponding beta.
- **Logaritmic compounding - given alfa below** - Same as above but the alfa is already available, and hence, the beta is used as input to the model to save some calculations for the VBA-macro.

As was concluded during the data analysis, *Chapter 5*, the only possible choice for the compounding distribution were the Emperical compounding distribution, hence the choice here was the "Empirical use "output"-sheet to insert distribution"

Calculations of reordering points

All these settings were made analogously for all the 106 items in the Excel file containing the VBA-macro. Then this Excel file was copied into 106 different files one for each of the studied items. In each file the specific data for each item was inserted in the following table.. The data inserted was:

- **Q** - the smallest common sub-batch of all Q, i.e. the greatest common divisor of all the different Q.
- **Q0, qi** - this is the multiple of Q for the central warehouse (Q0) and the retailers (qi).
- **L** - The lead time in days
- **h** - the holding cost per day, calculated as a holding cost in percent multiplied with the internal cost of the item divided by the number of days per year (365).
- **My** - The mean demand per day
- **Sigma** - Standard deviation per day
- **Target Fill-rates** - Target fill-rates as defined by Lantmännen

After inserting the data into each of the Excel files it was possible to calculate the new reorder points for each item by using multi echelon control.

Appendix H: Calculations for CO_2-emissions with NTM's method

Vehicle description		Unit
Vehicle type	Medium truck	
Vehicle max load	12	tonne

Fuel Parameters		Unit
Fuel type	Diesel MK 1	
Sulphur content	2	ppm
Energy content	35,3	MJ/l

Cargo/Load Description		Unit
Cargo type	Bulk	
Weight	5	tonne
Loading units	EU pallet	
Load capacity utiliza	50%	

Route description		Unit
Distance	300	km
Motorway	95%	
Urban	1%	
Rural	4%	

Fuel consumption	FC LCU 0% [l/km]	FC LCU 100% [l/km]
Motorway	0,155	0,188
Urban roads	0,221	0,33
Rural roads	0,147	0,192

Emission factors	CO	CO2	HC	CH4	NOx	PM	SOx	Source
Motorway	0,355	2615	0,0502	0,001	14,8	0,079	0,00125	Table 17
Urban roads	0,375	2615	0,0521	0,00104	15,3	0,083	0,0083	Table 19
Rural roads	0,454	2615	0,0692	0,00138	15,2	0,108	0,0083	Table 18

Calculations

Fuel

Road Type	FC LCU 50% [l/km]	Distance	FC Total [l]	Energy Usage [MJ]
Motorway	0,172	285	48,8775	1725,37575
Urban roads	0,276	3	0,8265	29,17545
Rural roads	0,170	12	2,034	71,8002
Summa:			51,738	1826,3514

Emissions

Road Type	CO	CO2	HC	CH4	NOx	PM	SOx
Motorway	17,352	127814,663	2,454	0,049	723,387	3,861	0,061
Urban roads	0,310	2161,298	0,043	0,001	12,645	0,069	0,007
Rural roads	0,923	5318,910	0,141	0,003	30,917	0,220	0,017
Summa:	18,585	135294,870	2,637	0,053	766,949	4,150	0,085

Allocation of emissions

CO	CO2	HC	CH4	NOx	PM	SOx
15,487405	112745,725	2,197886625	0,043787	639,124375	3,457995	0,070699

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
1	CW	2	2	-1	8		1.09E-02	5.47E-03	1.77E-01			
1	CW	2	2	-1	8			5.47E-03	1.33E-01			No
1	14	1	1	1	3	2.17E+00	1.09E-02	1.37E-03	3.70E-02	2.02E+00	7.51E+00	No
1	35	1	1	1	3	2.17E+00	1.09E-02	1.37E-03	3.70E-02	2.36E+00	7.51E+00	No
1	42	1	1	1	3	2.17E+00	1.09E-02	2.74E-03	5.23E-02	8.00E-02	7.51E+00	No
2	CW	3	2	-1	8			2.33E-02	2.09E-01			No
2	12	1	1	2	3	1.22E+01	6.13E-02	2.74E-03	7.40E-02	7.51E-01	3.32E+00	No
2	14	1	1	1	3	1.22E+01	6.13E-02	2.74E-03	5.23E-02	8.93E-01	3.32E+00	No
2	17	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.51E-01	3.32E+00	No
2	22	1	1	1	3	4.03E+00	6.13E-02	4.10E-03	8.27E-02	5.82E-01	3.32E+00	No
2	26	1	1	1	3	3.00E+00	6.13E-02	5.47E-03	9.05E-02	1.19E+00	7.95E+00	No
2	30	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.88E-01	3.32E+00	No
2	31	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.22E-01	3.32E+00	No
2	37	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	4.55E-01	3.32E+00	No
2	42	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	3.54E-02	3.32E+00	No
2	53	1	1	1	3	1.22E+01	6.13E-02	1.37E-03	3.70E-02	4.78E-01	3.32E+00	No
3	CW	2	2	-1	8			1.64E-02	1.77E-01			No
3	15	1	1	3	3	1.38E+01	6.92E-02	2.74E-03	7.40E-02	1.10E+00	4.72E+00	No
3	19	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.18E+00	4.72E+00	No
3	25	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.53E+00	1.11E+01	No
3	26	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.69E+00	1.13E+01	No
3	31	1	1	1	3	1.38E+01	6.92E-02	2.74E-03	5.23E-02	1.17E+00	4.72E+00	No
3	37	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.46E-01	4.72E+00	No
3	40	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	4.41E-01	4.72E+00	No
3	46	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	2.36E-01	4.72E+00	No
3	48	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.26E-01	4.72E+00	No
3	53	1	1	1	3	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.78E-01	4.72E+00	No
4	CW	3	2	-1	8			1.09E-02	2.17E-01			No
4	17	1	1	1	3	7.73E+00	3.88E-02	2.74E-03	5.23E-02	4.61E+00	1.80E+01	No
4	32	1	1	1	3	7.73E+00	3.88E-02	2.74E-03	5.23E-02	4.03E+00	1.80E+01	No
4	44	1	1	1	3	7.73E+00	3.88E-02	1.37E-03	3.70E-02	2.49E+00	1.80E+01	No
4	46	1	1	1	3	7.73E+00	3.88E-02	1.37E-03	3.70E-02	8.99E-01	1.80E+01	No
4	52	1	1	1	3	7.73E+00	3.88E-02	2.74E-03	5.23E-02	1.47E+00	1.80E+01	No
5	CW	8	2	-1	8			1.11E-01	9.04E-01			No
5	14	2	1	5	3	1.12E+00	4.67E-02	3.69E-02	3.88E-01	7.81E+02	2.91E+03	No
5	27	2	1	13	3	1.12E+00	4.67E-02	3.56E-02	5.77E-01	4.20E+02	2.91E+03	No
5	33	1	1	3	3	3.07E+00	4.67E-02	5.47E-03	1.48E-01	4.79E+02	2.91E+03	No
5	34	2	1	9	3	1.29E+00	4.67E-02	2.74E-02	5.23E-01	4.23E+02	2.91E+03	No
5	48	1	1	3	3	3.07E+00	4.67E-02	5.47E-03	1.48E-01	3.85E+02	2.91E+03	No
6	CW	5	2	-1	8			2.19E-02	2.67E-01			No
6	18	1	1	3	3	3.19E+00	4.85E-02	5.47E-03	1.48E-01	4.44E+00	1.60E+01	No
6	19	1	1	4	3	9.66E+00	4.85E-02	4.10E-03	1.11E-01	3.98E+00	1.60E+01	No
6	24	1	1	4	3	9.66E+00	4.85E-02	4.10E-03	1.11E-01	2.49E+00	1.60E+01	No
6	45	1	1	2	3	2.38E+00	4.85E-02	8.21E-03	1.57E-01	4.14E-01	1.60E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
7	**CW**	**5**	2	-1	8			2.46E-02	2.34E-01			Yes
7	**3**	**1**	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	5.05E-01	3.03E+00	Yes
7	**5**	**1**	1	4	4	1.23E-01	6.18E-04	4.10E-03	1.11E-01	4.48E-01	3.03E+00	Yes
7	**11**	**1**	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	6.64E-01	3.16E+00	Yes
7	**19**	**1**	1	1	3	1.23E-01	6.18E-04	1.37E-03	3.70E-02	2.67E-01	1.07E+00	No
7	**27**	**1**	1	2	3	1.23E-01	6.18E-04	2.74E-03	7.40E-02	1.55E-01	1.07E+00	No
7	**28**	**1**	1	1	3	1.23E-01	6.18E-04	1.37E-03	3.70E-02	1.41E-01	1.07E+00	No
7	**39**	**1**	1	1	3	1.23E-01	6.18E-04	1.37E-03	3.70E-02	1.79E-01	1.07E+00	No
7	**41**	**1**	1	1	3	1.23E-01	6.18E-04	1.37E-03	3.70E-02	9.09E-02	1.07E+00	No
7	**51**	**1**	1	1	3	1.23E-01	6.18E-04	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
7	**52**	**2**	2	4	3	1.23E-01	6.18E-04	8.21E-03	1.65E-01	8.72E-02	1.07E+00	No
8	**CW**	**6**	2	-2	8			2.87E-02	3.01E-01			Yes
8	**4**	**1**	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	5.50E-01	3.93E+00	Yes
8	**5**	**1**	1	3	4	1.02E+00	5.13E-03	4.10E-03	8.27E-02	5.82E-01	3.93E+00	Yes
8	**10**	**2**	1	2	4	1.02E+00	5.13E-03	5.47E-03	9.05E-02	4.60E-01	3.93E+00	Yes
8	**15**	**1**	1	3	3	1.02E+00	5.13E-03	2.74E-03	7.40E-02	3.26E-01	1.39E+00	No
8	**17**	**1**	1	1	3	1.02E+00	5.13E-03	4.10E-03	6.40E-02	3.57E-01	1.39E+00	No
8	**25**	**1**	1	1	3	1.02E+00	5.13E-03	1.37E-03	3.70E-02	4.53E-01	3.28E+00	No
8	**35**	**1**	1	1	3	1.02E+00	5.13E-03	1.37E-03	3.70E-02	4.39E-01	1.39E+00	No
8	**46**	**1**	1	1	3	1.02E+00	5.13E-03	1.37E-03	3.70E-02	6.96E-02	1.39E+00	No
8	**52**	**1**	1	1	3	1.02E+00	5.13E-03	1.37E-03	3.70E-02	1.13E-01	1.39E+00	No
8	**53**	**2**	1	1	3	1.02E+00	5.13E-03	5.47E-03	7.38E-02	2.00E-01	1.39E+00	No
9	**CW**	**2**	2	-1	8			5.47E-03	9.06E-02			No
9	**18**	**1**	1	1	3	8.10E-03	4.07E-05	1.37E-03	3.70E-02	2.38E-01	8.58E-01	No
9	**35**	**1**	1	3	3	8.10E-03	4.07E-05	2.74E-03	7.40E-02	2.70E-01	8.58E-01	No
9	**47**	**1**	1	1	3	8.10E-03	4.07E-05	1.37E-03	3.70E-02	1.15E-01	8.58E-01	No
10	**CW**	**4**	2	-1	8			1.64E-02	3.22E-01			No
10	**21**	**1**	1	4	3	1.83E-01	9.21E-04	4.10E-03	1.11E-01	8.99E-01	4.50E+00	No
10	**45**	**3**	2	11	3	1.83E-01	9.21E-04	1.09E-02	2.96E-01	1.17E-01	4.50E+00	No
10	**53**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	6.47E-01	4.50E+00	No
11	**CW**	**13**	2	-3	8			6.70E-02	5.51E-01			Yes
11	**9**	**1**	1	3	4	3.83E-01	1.93E-03	2.74E-03	7.40E-02	3.55E+00	2.60E+01	Yes
11	**10**	**1**	1	1	4	3.83E-01	1.93E-03	1.37E-03	3.70E-02	2.93E+00	2.51E+01	Yes
11	**13**	**1**	1	4	3	3.83E-01	1.93E-03	4.10E-03	1.11E-01	2.03E+00	8.90E+00	No
11	**14**	**2**	2	4	3	3.83E-01	1.93E-03	8.21E-03	1.38E-01	2.39E+00	8.90E+00	No
11	**21**	**2**	1	3	3	3.83E-01	1.93E-03	5.47E-03	1.05E-01	1.78E+00	8.90E+00	No
11	**31**	**4**	2	6	3	3.83E-01	1.93E-03	2.05E-02	2.53E-01	2.20E+00	8.90E+00	No
11	**38**	**1**	1	3	3	3.83E-01	1.93E-03	2.74E-03	7.40E-02	1.54E+00	8.90E+00	No
11	**41**	**3**	2	11	3	3.83E-01	1.93E-03	1.09E-02	2.96E-01	7.54E-01	8.90E+00	No
11	**46**	**1**	1	1	3	3.83E-01	1.93E-03	2.74E-03	5.23E-02	4.44E-01	8.90E+00	No
11	**53**	**2**	1	9	3	3.83E-01	1.93E-03	8.21E-03	2.22E-01	1.28E+00	8.90E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
12	CW	6	2	-1	8			3.14E-02	4.12E-01			No
12	17	3	2	6	3	6.62E-02	3.33E-04	1.09E-02	2.15E-01	8.24E-02	3.22E-01	No
12	23	3	2	10	3	6.62E-02	3.33E-04	1.09E-02	2.96E-01	5.43E-02	3.22E-01	No
12	35	1	1	2	3	6.62E-02	3.33E-04	2.74E-03	7.40E-02	1.01E-01	3.22E-01	No
12	44	2	1	4	3	6.62E-02	3.33E-04	6.83E-03	1.52E-01	4.45E-02	3.22E-01	No
13	CW	3	2	-1	8			1.09E-02	1.52E-01			No
13	16	1	1	1	3	3.51E+00	1.76E-02	2.74E-03	5.23E-02	1.01E+00	3.97E+00	No
13	20	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	1.16E+00	3.97E+00	No
13	27	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.73E-01	3.97E+00	No
13	28	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.23E-01	3.97E+00	No
13	33	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	6.53E-01	3.97E+00	No
13	37	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.44E-01	3.97E+00	No
13	48	1	1	1	3	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.26E-01	3.97E+00	No
14	CW	133	3	-25	8			1.34E+00	7.95E+00			Yes
14	9	4	2	22	4	1.80E-01	9.02E-04	2.05E-02	5.55E-01	1.58E+00	1.16E+01	Yes
14	15	43	2	63	3	1.80E-01	9.02E-04	2.30E-01	2.93E+00	9.27E-01	3.97E+00	No
14	16	32	2	70	3	5.93E-02	9.02E-04	3.34E-01	4.06E+00	1.01E+00	3.97E+00	No
14	19	28	2	78	3	1.80E-01	9.02E-04	1.48E-01	2.73E+00	9.88E-01	3.97E+00	No
14	27	10	2	50	3	1.80E-01	9.02E-04	4.92E-02	1.33E+00	5.73E-01	3.97E+00	No
14	31	5	2	11	3	1.80E-01	9.02E-04	2.19E-02	4.05E-01	9.82E-01	3.97E+00	No
14	32	15	2	37	3	1.80E-01	9.02E-04	7.80E-02	1.34E+00	8.87E-01	3.97E+00	No
14	33	17	2	46	3	1.80E-01	9.02E-04	8.76E-02	1.62E+00	6.53E-01	3.97E+00	No
14	46	31	2	79	3	5.93E-02	9.02E-04	3.20E-01	4.08E+00	1.98E-01	3.97E+00	No
14	53	9	2	39	3	1.80E-01	9.02E-04	4.79E-02	1.12E+00	5.70E-01	3.97E+00	No
15	CW	5	2	-1	8			2.19E-02	3.05E-01			No
15	16	2	1	5	3	2.39E-01	1.20E-03	5.47E-03	1.48E-01	1.01E+00	3.97E+00	No
15	27	2	1	5	3	2.39E-01	1.20E-03	5.47E-03	1.48E-01	5.73E-01	3.97E+00	No
15	42	3	2	5	3	2.39E-01	1.20E-03	1.09E-02	2.09E-01	4.23E-02	3.97E+00	No
16	CW	7	2	-2	8			6.70E-02	3.60E-01			Yes
16	1	1	1	1	4	7.02E+00	3.53E-02	1.37E-03	3.70E-02	2.89E+01	1.45E+02	Yes
16	5	1	1	3	4	7.02E+00	3.53E-02	2.74E-03	7.40E-02	2.14E+01	1.45E+02	Yes
16	8	1	1	1	4	7.02E+00	3.53E-02	1.37E-03	3.70E-02	1.63E+01	1.47E+02	Yes
16	13	2	1	2	3	1.73E+00	3.53E-02	1.09E-02	1.38E-01	1.17E+01	5.13E+01	No
16	17	1	1	2	3	2.32E+00	3.53E-02	8.21E-03	1.17E-01	1.31E+01	5.13E+01	No
16	23	2	1	2	3	1.73E+00	3.53E-02	1.64E-02	1.65E-01	8.66E+00	5.13E+01	No
16	28	2	1	3	3	7.02E+00	3.53E-02	5.47E-03	1.05E-01	6.76E+00	5.13E+01	No
16	30	1	1	3	3	7.02E+00	3.53E-02	2.74E-03	7.40E-02	1.37E+01	5.13E+01	No
16	36	1	1	2	3	2.32E+00	3.53E-02	6.84E-03	9.77E-02	1.03E+01	5.13E+01	No
16	47	2	1	2	3	1.73E+00	3.53E-02	1.09E-02	1.57E-01	6.89E+00	5.13E+01	No
17	CW	1	1	-1	8			4.10E-03	6.41E-02			No
17	42	1	1	1	3	2.69E+00	1.35E-02	1.37E-03	3.70E-02	5.26E-02	4.93E+00	No
17	43	1	1	1	3	2.69E+00	1.35E-02	1.37E-03	3.70E-02	2.35E-01	4.93E+00	No
17	46	1	1	1	3	2.69E+00	1.35E-02	1.37E-03	3.70E-02	2.46E-01	4.93E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
18	CW	7	2	-2	8			3.42E-02	2.91E-01			No
18	15	2	1	5	3	2.37E+00	1.19E-02	6.84E-03	1.52E-01	3.21E+00	1.37E+01	No
18	27	2	1	3	3	2.37E+00	1.19E-02	5.47E-03	1.05E-01	1.98E+00	1.37E+01	No
18	35	1	1	3	3	2.37E+00	1.19E-02	2.74E-03	7.40E-02	4.32E+00	1.37E+01	No
18	36	2	2	4	3	2.37E+00	1.19E-02	8.21E-03	1.38E-01	2.76E+00	1.37E+01	No
18	42	2	1	3	3	2.37E+00	1.19E-02	8.21E-03	1.28E-01	1.46E-01	1.37E+01	No
18	44	1	1	3	3	2.37E+00	1.19E-02	2.74E-03	7.40E-02	1.90E+00	1.37E+01	No
19	CW	6	2	-2	8			2.87E-02	5.05E-01			No
19	25	1	1	1	3	6.45E-01	3.24E-03	1.37E-03	3.70E-02	2.75E+00	2.00E+01	No
19	43	1	1	1	3	6.45E-01	3.24E-03	1.37E-03	3.70E-02	4.04E-01	8.47E+00	No
19	45	5	2	17	3	6.45E-01	3.24E-03	2.60E-02	4.80E-01	2.20E-01	8.47E+00	No
20	CW	28	2	-5	8			1.42E-01	1.57E+00			No
20	22	15	2	33	3	3.16E-02	1.59E-04	7.66E-02	1.21E+00	3.76E-02	2.14E-01	No
20	34	6	2	15	3	3.16E-02	1.59E-04	2.74E-02	5.25E-01	3.12E-02	2.14E-01	No
20	43	5	2	16	3	3.16E-02	1.59E-04	2.46E-02	4.96E-01	1.02E-02	2.14E-01	No
20	48	3	2	14	3	3.16E-02	1.59E-04	1.37E-02	3.70E-01	2.84E-02	2.14E-01	No
21	CW	1	1	-1	8			1.64E-02	2.19E-01			No
21	15	1	1	0	3	1.74E+01	6.31E-01	1.37E-03	3.70E-02	7.52E+02	3.22E+03	No
21	16	1	1	1	3	1.20E+01	6.31E-01	4.10E-03	6.40E-02	8.19E+02	3.22E+03	No
21	28	1	1	0	3	1.74E+01	6.31E-01	1.37E-03	3.70E-02	4.24E+02	3.22E+03	No
21	34	1	1	1	3	9.88E+00	6.31E-01	8.21E-03	9.03E-02	4.68E+02	3.22E+03	No
21	42	1	1	0	3	1.74E+01	6.31E-01	1.37E-03	3.70E-02	3.43E+01	3.22E+03	No
22	CW	3	2	-1	8			1.50E-02	2.76E-01			No
22	25	1	1	1	3	7.26E+00	3.65E-02	1.37E-03	3.70E-02	1.01E+01	7.30E+01	No
22	42	1	1	1	3	7.26E+00	3.65E-02	1.37E-03	3.70E-02	3.30E-01	3.10E+01	No
22	45	2	1	1	3	7.26E+00	3.65E-02	5.47E-03	7.38E-02	8.04E-01	3.10E+01	No
22	46	1	1	1	3	7.26E+00	3.65E-02	2.74E-03	5.23E-02	1.55E+00	3.10E+01	No
22	51	1	1	1	3	7.26E+00	3.65E-02	2.74E-03	5.23E-02	2.09E+00	3.10E+01	No
22	52	1	1	1	3	7.26E+00	3.65E-02	1.37E-03	3.70E-02	2.52E+00	3.10E+01	No
23	CW	38	3	-13	8			3.82E-01	1.62E+00			No
23	12	3	2	5	3	9.68E-01	4.86E-03	1.09E-02	1.81E-01	1.94E+00	8.58E+00	No
23	15	6	2	6	3	3.19E-01	4.86E-03	5.31E-02	4.32E-01	2.00E+00	8.58E+00	No
23	18	5	2	6	3	9.68E-01	4.86E-03	2.46E-02	2.75E-01	2.38E+00	8.58E+00	No
23	20	3	2	8	3	9.68E-01	4.86E-03	1.37E-02	2.67E-01	2.50E+00	8.58E+00	No
23	27	8	2	5	3	9.68E-01	4.86E-03	3.97E-02	3.43E-01	1.24E+00	8.58E+00	No
23	36	4	2	5	3	9.68E-01	4.86E-03	1.78E-02	2.30E-01	1.73E+00	8.58E+00	No
23	37	5	2	6	3	9.68E-01	4.86E-03	2.32E-02	2.78E-01	1.18E+00	8.58E+00	No
23	42	10	2	8	3	2.38E-01	4.86E-03	1.05E-01	6.92E-01	9.14E-02	8.58E+00	No
23	45	6	2	8	3	3.19E-01	4.86E-03	5.74E-02	4.93E-01	2.23E-01	8.58E+00	No
23	46	7	2	7	3	9.68E-01	4.86E-03	3.69E-02	3.62E-01	4.28E-01	8.58E+00	No
24	CW	2	2	-1	8			6.84E-03	1.82E-01			No
24	35	1	1	1	3	2.33E+00	1.17E-02	4.10E-03	6.40E-02	5.40E-01	1.72E+00	No
24	36	1	1	1	3	2.33E+00	1.17E-02	2.74E-03	5.23E-02	3.45E-01	1.72E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
25	CW	3	2	-1	8			1.37E-02	2.06E-01			Yes
25	8	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	1.60E+00	1.45E+01	Yes
25	14	1	1	1	3	2.91E-01	1.46E-03	1.37E-03	3.70E-02	1.35E+00	5.04E+00	No
25	22	2	1	7	3	2.91E-01	1.46E-03	6.84E-03	1.85E-01	8.83E-01	5.04E+00	No
25	29	1	1	1	3	2.91E-01	1.46E-03	1.37E-03	3.70E-02	6.00E-01	5.04E+00	No
25	43	1	1	1	3	2.91E-01	1.46E-03	1.37E-03	3.70E-02	2.41E-01	5.04E+00	No
25	50	1	1	1	3	2.91E-01	1.46E-03	1.37E-03	3.70E-02	9.04E-01	5.04E+00	No
26	CW	3	2	-1	8			2.74E-02	2.94E-01			No
26	13	1	1	1	3	3.99E+00	8.14E-02	5.47E-03	7.38E-02	2.53E+01	1.11E+02	No
26	14	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.98E+01	1.11E+02	No
26	17	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.84E+01	1.11E+02	No
26	19	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.76E+01	1.11E+02	No
26	20	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	3.23E+01	1.11E+02	No
26	27	1	1	1	3	3.99E+00	8.14E-02	5.47E-03	7.38E-02	1.60E+01	1.11E+02	No
26	34	1	1	1	3	3.99E+00	8.14E-02	5.47E-03	7.38E-02	1.61E+01	1.11E+02	No
26	36	1	1	1	3	1.62E+01	8.14E-02	2.74E-03	5.23E-02	2.23E+01	1.11E+02	No
26	43	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	5.29E+00	1.11E+02	No
26	49	1	1	1	3	1.62E+01	8.14E-02	1.37E-03	3.70E-02	1.68E+01	1.11E+02	No
27	CW	9	2	-2	8			4.38E-02	3.09E-01			No
27	14	1	1	2	3	2.42E-01	1.22E-03	4.10E-03	8.27E-02	5.76E-02	2.14E-01	No
27	17	2	1	3	3	2.42E-01	1.22E-03	8.21E-03	1.28E-01	5.49E-02	2.14E-01	No
27	18	1	1	3	3	2.42E-01	1.22E-03	2.74E-03	7.40E-02	5.96E-02	2.14E-01	No
27	26	1	1	1	3	2.42E-01	1.22E-03	1.37E-03	3.70E-02	7.70E-02	5.13E-01	No
27	31	1	1	3	3	2.42E-01	1.22E-03	2.74E-03	7.40E-02	5.31E-02	2.14E-01	No
27	33	2	1	3	3	2.42E-01	1.22E-03	5.47E-03	1.05E-01	3.53E-02	2.14E-01	No
27	34	1	1	3	3	2.42E-01	1.22E-03	2.74E-03	7.40E-02	3.12E-02	2.14E-01	No
27	35	2	1	3	3	2.42E-01	1.22E-03	5.47E-03	1.05E-01	6.76E-02	2.14E-01	No
27	46	2	1	3	3	2.42E-01	1.22E-03	5.47E-03	1.05E-01	1.07E-02	2.14E-01	No
27	50	2	1	5	3	2.42E-01	1.22E-03	5.47E-03	1.48E-01	3.85E-02	2.14E-01	No
28	CW	3	2	-1	8			1.23E-02	1.52E-01			No
28	22	1	1	2	3	2.11E+00	1.06E-02	2.74E-03	7.40E-02	1.71E+00	9.76E+00	No
28	24	1	1	1	3	2.11E+00	1.06E-02	1.37E-03	3.70E-02	1.52E+00	9.76E+00	No
28	27	2	1	2	3	2.11E+00	1.06E-02	5.47E-03	1.05E-01	1.41E+00	9.76E+00	No
28	36	1	1	2	3	2.11E+00	1.06E-02	2.74E-03	7.40E-02	1.96E+00	9.76E+00	No
29	CW	4	2	-2	8			5.34E-02	4.35E-01			No
29	13	1	1	1	3	2.82E+00	1.02E-01	1.09E-02	1.04E-01	3.71E+01	1.63E+02	No
29	22	1	1	1	3	5.02E+00	1.02E-01	4.10E-03	6.40E-02	2.85E+01	1.63E+02	No
29	28	1	1	1	3	2.82E+00	1.02E-01	1.09E-02	1.04E-01	2.15E+01	1.63E+02	No
29	33	1	1	1	3	6.73E+00	1.02E-01	2.74E-03	5.23E-02	2.68E+01	1.63E+02	No
29	37	1	1	1	3	3.31E+00	1.02E-01	6.84E-03	8.25E-02	2.23E+01	1.63E+02	No
29	38	1	1	1	3	3.31E+00	1.02E-01	6.84E-03	8.25E-02	2.81E+01	1.63E+02	No
29	46	1	1	1	3	5.02E+00	1.02E-01	4.10E-03	6.40E-02	8.13E+00	1.63E+02	No
29	47	1	1	1	3	2.04E+01	1.02E-01	1.37E-03	3.70E-02	2.19E+01	1.63E+02	No
29	49	1	1	1	3	6.73E+00	1.02E-01	2.74E-03	5.23E-02	2.47E+01	1.63E+02	No
29	52	1	1	1	3	6.73E+00	1.02E-01	2.74E-03	5.23E-02	1.32E+01	1.63E+02	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
30	**CW**	**1**	1	-1	8			2.74E-03	1.22E-01			No
30	**42**	**1**	1	1	3	6.81E+00	3.42E-02	2.74E-03	5.23E-02	3.45E-01	3.24E+01	No
31	**CW**	**8**	2	-2	8			4.10E-02	3.89E-01			No
31	**25**	**2**	1	3	3	3.85E+00	1.93E-02	5.47E-03	1.05E-01	4.88E+01	3.54E+02	No
31	**27**	**1**	1	4	3	3.85E+00	1.93E-02	4.10E-03	1.11E-01	2.17E+01	1.50E+02	No
31	**35**	**1**	1	1	3	3.85E+00	1.93E-02	2.74E-03	5.23E-02	4.73E+01	1.50E+02	No
31	**36**	**2**	1	9	3	3.85E+00	1.93E-02	8.21E-03	2.22E-01	3.02E+01	1.50E+02	No
31	**45**	**3**	2	4	3	3.85E+00	1.93E-02	1.23E-02	1.92E-01	3.89E+00	1.50E+02	No
31	**46**	**2**	2	5	3	3.85E+00	1.93E-02	8.20E-03	1.65E-01	7.49E+00	1.50E+02	No
32	**CW**	**3**	2	-1	8			1.23E-02	1.48E-01			No
32	**39**	**1**	1	1	3	1.43E+00	7.20E-03	1.37E-03	3.70E-02	2.33E-01	1.39E+00	No
32	**43**	**1**	1	1	3	1.43E+00	7.07E-03	1.37E-03	3.70E-02	6.66E-02	1.39E+00	No
32	**45**	**2**	1	2	3	1.43E+00	7.07E-03	6.84E-03	1.11E-01	3.62E-02	1.39E+00	No
32	**46**	**1**	1	2	3	1.43E+00	7.07E-03	2.74E-03	7.40E-02	6.96E-02	1.39E+00	No
33	**CW**	**1**	1	-1	8			1.37E-03	3.70E-02			No
33	**42**	**1**	1	1	3	1.90E+00	9.56E-03	1.37E-03	3.70E-02	8.00E-03	7.51E-01	No
34	**CW**	**4**	2	-1	8			2.05E-02	2.61E-01			No
34	**22**	**1**	1	4	3	2.72E+00	1.37E-02	4.10E-03	1.11E-01	2.23E+01	1.27E+02	No
34	**24**	**2**	1	5	3	2.72E+00	1.37E-02	5.47E-03	1.48E-01	1.98E+01	1.27E+02	No
34	**27**	**1**	1	2	3	2.72E+00	1.37E-02	2.74E-03	7.40E-02	1.84E+01	1.27E+02	No
34	**29**	**1**	1	1	3	2.72E+00	1.37E-02	2.74E-03	5.23E-02	1.52E+01	1.27E+02	No
34	**38**	**1**	1	4	3	2.72E+00	1.37E-02	4.10E-03	1.11E-01	2.20E+01	1.27E+02	No
34	**51**	**1**	1	1	3	2.72E+00	1.37E-02	1.37E-03	3.70E-02	8.58E+00	1.27E+02	No
35	**CW**	**2**	2	-1	8			8.21E-03	1.52E-01			No
35	**19**	**1**	1	1	3	4.20E-01	2.11E-03	1.37E-03	3.70E-02	3.21E-01	1.29E+00	No
35	**35**	**1**	1	3	3	4.20E-01	2.11E-03	2.74E-03	7.40E-02	4.05E-01	1.29E+00	No
35	**40**	**1**	1	1	3	4.20E-01	2.11E-03	2.74E-03	5.23E-02	1.20E-01	1.29E+00	No
35	**41**	**1**	1	1	3	4.20E-01	2.11E-03	1.37E-03	3.70E-02	1.09E-01	1.29E+00	No
36	**CW**	**2**	1	-1	8			1.23E-02	1.52E-01			Yes
36	**5**	**1**	1	0	4	1.52E+01	2.32E-01	1.37E-03	3.70E-02	1.64E+02	1.11E+03	Yes
36	**22**	**1**	1	0	3	1.52E+01	2.32E-01	1.37E-03	3.70E-02	6.88E+01	3.92E+02	No
36	**32**	**1**	1	0	3	1.52E+01	2.32E-01	1.37E-03	3.70E-02	8.78E+01	3.92E+02	No
36	**44**	**1**	1	2	3	5.56E+00	2.32E-01	5.47E-03	1.17E-01	5.43E+01	3.92E+02	No
36	**48**	**1**	1	1	3	7.49E+00	2.32E-01	2.74E-03	7.40E-02	5.20E+01	3.92E+02	No
37	**CW**	**1**	1	-1	8			1.92E-02	2.40E-01			No
37	**15**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	7.67E+00	3.28E+01	No
37	**16**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	8.36E+00	3.28E+01	No
37	**19**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	8.17E+00	3.28E+01	No
37	**22**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	5.75E+00	3.28E+01	No
37	**24**	**1**	1	1	3	1.87E+01	9.85E-01	2.74E-03	5.23E-02	5.10E+00	3.28E+01	No
37	**25**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	1.07E+01	7.73E+01	No
37	**31**	**1**	1	1	3	1.54E+01	9.85E-01	4.10E-03	6.40E-02	8.12E+00	3.28E+01	No
37	**42**	**1**	1	1	3	1.87E+01	9.85E-01	2.74E-03	5.23E-02	3.50E-01	3.28E+01	No
37	**43**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	1.57E+00	3.28E+01	No
37	**49**	**1**	1	0	3	2.36E+01	9.85E-01	1.37E-03	3.70E-02	4.97E+00	3.28E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
38	CW	12	2	-2	8			1.20E-01	8.75E-01			No
38	13	2	1	8	3	2.28E+00	1.14E-02	8.21E-03	2.22E-01	2.47E+00	1.08E+01	No
38	27	5	2	9	3	2.28E+00	1.14E-02	2.46E-02	3.84E-01	1.56E+00	1.08E+01	No
38	31	4	2	8	3	2.28E+00	1.14E-02	2.05E-02	3.32E-01	2.68E+00	1.08E+01	No
38	42	5	2	9	3	2.28E+00	1.14E-02	2.60E-02	3.86E-01	1.15E-01	1.08E+01	No
38	45	2	1	8	3	2.28E+00	1.14E-02	8.21E-03	2.22E-01	2.81E-01	1.08E+01	No
38	46	2	1	8	3	2.28E+00	1.14E-02	8.21E-03	2.22E-01	5.41E-01	1.08E+01	No
38	47	2	1	8	3	2.28E+00	1.14E-02	8.21E-03	2.22E-01	1.46E+00	1.08E+01	No
38	49	4	2	8	3	2.28E+00	1.14E-02	1.64E-02	3.14E-01	1.64E+00	1.08E+01	No
39	CW	1	1	-1	8			4.10E-03	1.27E-01			No
39	42	1	1	1	3	9.02E+00	2.79E-01	2.74E-03	5.23E-02	1.71E-01	1.61E+01	No
39	48	1	1	0	3	1.37E+01	2.79E-01	1.37E-03	3.70E-02	2.13E+00	1.61E+01	No
40	CW	2	2	-1	14			9.57E-03	1.33E-01			No
40	20	1	1	3	3	1.49E+01	7.49E-02	2.74E-03	7.40E-02	4.06E+01	1.39E+02	No
40	22	1	1	2	3	4.92E+00	7.49E-02	4.10E-03	8.26E-02	2.44E+01	1.39E+02	No
40	42	1	1	3	3	1.49E+01	7.49E-02	2.74E-03	7.40E-02	1.49E+00	1.39E+02	No
41	CW	28	3	1	15			4.49E-01	2.34E+00			No
41	34	2	1	6	3	5.28E+00	2.65E-02	6.84E-03	1.85E-01	7.80E+00	5.36E+01	No
41	42	5	1	15	3	4.16E-01	2.65E-02	1.24E-01	1.20E+00	5.71E-01	5.36E+01	No
41	43	3	1	11	3	6.37E-01	2.65E-02	5.34E-02	7.50E-01	2.56E+00	5.36E+01	No
41	45	7	2	11	3	4.16E-01	2.65E-02	1.60E-01	1.23E+00	1.39E+00	5.36E+01	No
41	46	3	1	9	3	8.58E-01	2.65E-02	3.28E-02	5.43E-01	2.68E+00	5.36E+01	No
41	51	3	1	24	3	6.37E-01	2.65E-02	5.06E-02	1.06E+00	3.61E+00	5.36E+01	No
41	52	3	1	11	3	1.30E+00	2.65E-02	2.19E-02	4.56E-01	4.36E+00	5.36E+01	No
42	CW	2	2	-1	12			5.47E-03	1.28E-01			Yes
42	6	1	1	1	4	3.14E+01	1.58E-01	1.37E-03	3.70E-02	7.66E+02	7.57E+03	Yes
42	53	1	1	1	3	5.10E+00	1.58E-01	4.10E-03	6.40E-02	3.85E+02	2.68E+03	No
43	CW	1	1	-1	15			2.74E-03	5.23E-02			No
43	31	1	1	1	3	3.47E-01	1.75E-03	1.37E-03	3.70E-02	2.39E-01	9.65E-01	No
43	49	1	1	1	3	3.47E-01	1.75E-03	1.37E-03	3.70E-02	1.46E-01	9.65E-01	No
44	CW	2	2	-1	15			8.21E-03	2.05E-01			No
44	15	2	1	1	3	5.09E+00	2.56E-02	5.47E-03	7.38E-02	1.25E+01	5.36E+01	No
44	53	1	1	1	3	5.09E+00	2.21E-02	2.74E-03	5.23E-02	7.71E+00	5.36E+01	No
45	CW	7	2	-2	12			3.56E-02	2.86E-01			Yes
45	5	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.34E+00	9.08E+00	Yes
45	6	2	1	4	4	1.85E+00	2.82E-02	1.09E-02	1.81E-01	9.19E-01	9.08E+00	Yes
45	10	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.06E+00	9.08E+00	Yes
45	13	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	7.34E-01	3.22E+00	No
45	14	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	8.65E-01	3.22E+00	No
45	15	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	7.52E-01	3.22E+00	No
45	22	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	5.64E-01	3.22E+00	No
45	25	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.04E+00	7.58E+00	No
45	30	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	8.59E-01	3.22E+00	No
45	44	1	1	3	3	5.60E+00	2.82E-02	2.74E-03	7.40E-02	4.45E-01	3.22E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
46	**CW**	**8**	2	-2	10			3.83E-02	3.16E-01			Yes
46	**9**	**1**	1	1	4	5.33E+00	2.68E-02	1.37E-03	3.70E-02	4.70E-01	3.44E+00	Yes
46	**15**	**1**	1	3	3	5.33E+00	2.68E-02	2.74E-03	7.40E-02	2.76E-01	1.18E+00	No
46	**21**	**1**	1	3	3	5.33E+00	2.68E-02	2.74E-03	7.40E-02	2.36E-01	1.18E+00	No
46	**23**	**1**	1	3	3	5.33E+00	2.68E-02	2.74E-03	7.40E-02	1.99E-01	1.18E+00	No
46	**34**	**1**	1	4	3	5.33E+00	2.68E-02	4.10E-03	1.11E-01	1.72E-01	1.18E+00	No
46	**42**	**2**	1	3	3	5.33E+00	2.68E-02	5.47E-03	1.05E-01	1.26E-02	1.18E+00	No
46	**45**	**1**	1	1	3	5.33E+00	2.68E-02	1.37E-03	3.70E-02	3.06E-02	1.18E+00	No
46	**52**	**2**	1	5	3	1.76E+00	2.68E-02	1.09E-02	2.09E-01	9.59E-02	1.18E+00	No
46	**53**	**2**	1	3	3	5.33E+00	2.68E-02	6.84E-03	1.11E-01	1.70E-01	1.18E+00	No
47	**CW**	**4**	2	-1	10			1.64E-02	1.72E-01			Yes
47	**1**	**1**	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	1.82E+00	9.08E+00	Yes
47	**5**	**1**	1	1	4	1.24E+01	6.23E-02	2.74E-03	5.23E-02	1.34E+00	9.08E+00	Yes
47	**23**	**1**	1	2	3	1.24E+01	6.23E-02	2.74E-03	7.40E-02	5.43E-01	3.22E+00	No
47	**27**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.64E-01	3.22E+00	No
47	**34**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.68E-01	3.22E+00	No
47	**42**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	3.43E-02	3.22E+00	No
47	**47**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.33E-01	3.22E+00	No
47	**48**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.27E-01	3.22E+00	No
47	**49**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.87E-01	3.22E+00	No
47	**50**	**1**	1	1	3	1.24E+01	6.23E-02	1.37E-03	3.70E-02	5.77E-01	3.22E+00	No
48	**CW**	**2**	2	-1	10			8.21E-03	1.71E-01			Yes
48	**7**	**1**	1	1	4	1.13E+01	5.69E-02	2.74E-03	5.23E-02	1.47E+00	1.23E+01	Yes
48	**8**	**1**	1	1	4	1.13E+01	5.69E-02	2.74E-03	5.23E-02	1.36E+00	1.23E+01	Yes
48	**40**	**1**	1	1	3	1.13E+01	5.69E-02	1.37E-03	3.70E-02	4.01E-01	4.29E+00	No
48	**48**	**1**	1	1	3	1.13E+01	5.69E-02	1.37E-03	3.70E-02	5.69E-01	4.29E+00	No
49	**CW**	**1**	1	-1	14			2.74E-03	1.06E-01			No
49	**51**	**1**	1	1	3	1.78E+01	1.14E+00	2.74E-03	5.23E-02	7.22E+02	1.07E+04	No
50	**CW**	**2**	2	-1	10			1.92E-02	2.48E-01			No
50	**12**	**1**	1	1	3	1.10E+01	3.99E-01	2.74E-03	5.23E-02	4.36E+00	1.93E+01	No
50	**19**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	4.81E+00	1.93E+01	No
50	**27**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	2.79E+00	1.93E+01	No
50	**31**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	4.77E+00	1.93E+01	No
50	**35**	**1**	1	1	3	1.10E+01	3.99E-01	2.74E-03	5.23E-02	6.08E+00	1.93E+01	No
50	**36**	**1**	1	1	3	1.10E+01	3.99E-01	2.74E-03	5.23E-02	3.88E+00	1.93E+01	No
50	**39**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	3.22E+00	1.93E+01	No
50	**42**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	2.06E-01	1.93E+01	No
50	**43**	**1**	1	0	3	1.29E+01	3.99E-01	1.37E-03	3.70E-02	9.21E-01	1.93E+01	No
50	**47**	**1**	1	1	3	1.10E+01	3.99E-01	2.74E-03	5.23E-02	2.60E+00	1.93E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
51	CW	5	2	-1	10			2.46E-02	2.50E-01			No
51	19	3	2	4	3	1.48E+00	7.44E-03	1.09E-02	1.73E-01	2.67E-01	1.07E+00	No
51	21	1	1	1	3	1.48E+00	7.44E-03	1.37E-03	3.70E-02	2.14E-01	1.07E+00	No
51	23	1	1	1	3	1.48E+00	7.44E-03	2.74E-03	5.23E-02	1.81E-01	1.07E+00	No
51	26	1	1	2	3	1.48E+00	7.44E-03	2.74E-03	7.40E-02	3.85E-01	2.57E+00	No
51	29	1	1	2	3	1.48E+00	7.44E-03	2.74E-03	7.40E-02	1.28E-01	1.07E+00	No
51	37	1	1	1	3	1.48E+00	7.44E-03	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
51	45	1	1	1	3	1.48E+00	7.44E-03	1.37E-03	3.70E-02	2.78E-02	1.07E+00	No
51	51	1	1	1	3	1.48E+00	7.44E-03	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
52	CW	3	2	-1	10			1.50E-02	1.60E-01			Yes
52	7	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	7.37E-01	6.17E+00	Yes
52	16	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.46E-01	2.14E+00	No
52	17	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.49E-01	2.14E+00	No
52	19	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.34E-01	2.14E+00	No
52	20	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	6.24E-01	2.14E+00	No
52	23	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	3.62E-01	2.14E+00	No
52	35	1	1	1	3	9.73E-01	4.89E-03	2.74E-03	5.23E-02	6.76E-01	2.14E+00	No
52	41	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	1.82E-01	2.14E+00	No
52	43	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	1.02E-01	2.14E+00	No
52	50	1	1	1	3	9.73E-01	4.89E-03	1.37E-03	3.70E-02	3.85E-01	2.14E+00	No
53	CW	6	2	-1	10			2.60E-02	2.30E-01			Yes
53	3	1	1	1	4	6.23E+00	3.13E-02	2.74E-03	5.23E-02	5.55E+00	3.33E+01	Yes
53	6	1	1	2	4	6.23E+00	3.13E-02	4.10E-03	8.27E-02	3.37E+00	3.33E+01	Yes
53	8	1	1	2	4	6.23E+00	3.08E-02	2.74E-03	7.40E-02	3.75E+00	3.39E+01	Yes
53	15	1	1	2	3	6.23E+00	3.08E-02	4.10E-03	8.26E-02	2.76E+00	1.18E+01	No
53	17	1	1	1	3	6.23E+00	3.15E-02	1.37E-03	3.70E-02	3.02E+00	1.18E+01	No
53	19	1	1	2	3	6.23E+00	3.15E-02	2.74E-03	7.40E-02	2.94E+00	1.18E+01	No
53	20	1	1	1	3	6.23E+00	3.15E-02	1.37E-03	3.70E-02	3.43E+00	1.18E+01	No
53	33	1	1	2	3	6.23E+00	3.09E-02	2.74E-03	7.40E-02	1.94E+00	1.18E+01	No
53	35	1	1	1	3	6.23E+00	3.09E-02	1.37E-03	3.70E-02	3.72E+00	1.18E+01	No
53	36	1	1	2	3	6.23E+00	3.09E-02	2.74E-03	7.40E-02	2.37E+00	1.18E+01	No
54	CW	3	2	-1	10			2.33E-02	1.92E-01			Yes
54	10	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	4.24E+00	3.63E+01	Yes
54	17	1	1	1	3	9.49E+00	4.77E-02	1.37E-03	3.70E-02	3.30E+00	1.29E+01	No
54	26	1	1	3	3	9.49E+00	4.77E-02	2.74E-03	7.40E-02	4.62E+00	3.08E+01	No
54	32	1	1	1	3	9.49E+00	4.77E-02	1.37E-03	3.70E-02	2.88E+00	1.29E+01	No
54	35	1	1	1	3	9.49E+00	4.77E-02	1.37E-03	3.70E-02	4.05E+00	1.29E+01	No
54	41	1	1	2	3	3.13E+00	4.77E-02	5.47E-03	1.05E-01	1.09E+00	1.29E+01	No
54	42	1	1	2	3	9.49E+00	4.77E-02	4.10E-03	8.27E-02	1.37E-01	1.29E+01	No
54	45	1	1	1	3	9.49E+00	4.77E-02	1.37E-03	3.70E-02	3.34E-01	1.29E+01	No
54	48	1	1	3	3	9.49E+00	4.77E-02	2.74E-03	7.40E-02	1.71E+00	1.29E+01	No
54	50	1	1	1	3	9.49E+00	4.77E-02	1.37E-03	3.70E-02	2.31E+00	1.29E+01	No
55	CW	1	2	-1	15			2.74E-03	7.40E-02			No
55	31	1	1	2	3	7.31E+00	1.11E-01	2.74E-03	7.40E-02	1.33E+00	5.36E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
56	**CW**	**3**	2	-1	10			1.37E-02	1.91E-01			Yes
56	**6**	**1**	1	1	4	7.07E+00	3.55E-02	2.74E-03	5.23E-02	1.84E+00	1.82E+01	Yes
56	**8**	**1**	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	2.04E+00	1.85E+01	Yes
56	**11**	**1**	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	3.98E+00	1.90E+01	Yes
56	**15**	**1**	1	1	3	7.07E+00	3.55E-02	1.37E-03	3.70E-02	1.50E+00	6.43E+00	No
56	**34**	**1**	1	1	3	7.07E+00	3.55E-02	1.37E-03	3.70E-02	9.36E-01	6.43E+00	No
56	**41**	**1**	1	1	3	7.07E+00	3.55E-02	4.10E-03	6.40E-02	5.45E-01	6.43E+00	No
56	**52**	**1**	1	1	3	7.07E+00	3.55E-02	1.37E-03	3.70E-02	5.23E-01	6.43E+00	No
57	**CW**	**1**	1	-1	10			1.37E-03	3.70E-02			No
57	**38**	**1**	1	1	3	5.16E+00	2.59E-02	1.37E-03	3.70E-02	1.42E+00	8.26E+00	No
58	**CW**	**2**	2	-1	10			1.37E-02	1.56E-01			No
58	**24**	**1**	1	1	3	1.62E+01	8.15E-02	2.74E-03	5.23E-02	4.00E+00	2.57E+01	No
58	**26**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	9.24E+00	6.16E+01	No
58	**35**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	8.11E+00	2.57E+01	No
58	**42**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	2.74E-01	2.57E+01	No
58	**44**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.56E+00	2.57E+01	No
58	**47**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.46E+00	2.57E+01	No
58	**49**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.90E+00	2.57E+01	No
58	**51**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	1.73E+00	2.57E+01	No
58	**53**	**1**	1	1	3	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.70E+00	2.57E+01	No
59	**CW**	**4**	2	-1	10			1.64E-02	2.19E-01			No
59	**16**	**1**	1	1	3	3.95E+00	1.99E-02	2.74E-03	5.23E-02	2.73E-01	1.07E+00	No
59	**26**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	3.85E-01	2.57E+00	No
59	**32**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	2.40E-01	1.07E+00	No
59	**34**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	1.56E-01	1.07E+00	No
59	**37**	**1**	1	1	3	3.95E+00	1.99E-02	2.74E-03	5.23E-02	1.47E-01	1.07E+00	No
59	**42**	**1**	1	1	3	3.95E+00	1.99E-02	2.74E-03	5.23E-02	1.14E-02	1.07E+00	No
59	**43**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	5.12E-02	1.07E+00	No
59	**47**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	1.44E-01	1.07E+00	No
59	**52**	**1**	1	1	3	3.95E+00	1.99E-02	1.37E-03	3.70E-02	8.72E-02	1.07E+00	No
60	**CW**	**5**	2	-2	10			2.19E-02	2.60E-01			No
60	**13**	**1**	1	1	3	5.48E+00	2.76E-02	4.10E-03	6.40E-02	7.34E-02	3.22E-01	No
60	**17**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	8.24E-02	3.22E-01	No
60	**20**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	9.37E-02	3.22E-01	No
60	**21**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	6.42E-02	3.22E-01	No
60	**23**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	5.43E-02	3.22E-01	No
60	**26**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	1.16E-01	7.70E-01	No
60	**28**	**1**	1	1	3	5.48E+00	2.76E-02	1.37E-03	3.70E-02	4.24E-02	3.22E-01	No
60	**45**	**1**	1	1	3	5.48E+00	2.76E-02	2.74E-03	5.23E-02	8.34E-03	3.22E-01	No
60	**48**	**1**	1	1	3	5.48E+00	2.76E-02	2.74E-03	5.23E-02	4.27E-02	3.22E-01	No
60	**53**	**1**	1	1	3	5.48E+00	2.76E-02	4.10E-03	6.40E-02	4.62E-02	3.22E-01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
61	CW	2	2	-1	10		3.94E-01	3.97E-02	3.60E-01			Yes
61	1	1	1	0	4	1.93E+01	3.95E-01	1.37E-03	3.70E-02	1.82E+01	9.08E+01	Yes
61	5	1	1	1	4	7.50E+00	3.95E-01	4.10E-03	6.40E-02	1.34E+01	9.08E+01	Yes
61	6	1	1	0	4	1.93E+01	3.95E-01	1.37E-03	3.70E-02	9.19E+00	9.08E+01	Yes
61	17	1	1	1	3	7.50E+00	3.95E-01	4.10E-03	6.40E-02	8.24E+00	3.22E+01	No
61	19	1	1	1	3	1.09E+01	3.95E-01	2.74E-03	5.23E-02	8.01E+00	3.22E+01	No
61	21	1	1	1	3	7.50E+00	3.95E-01	5.47E-03	7.38E-02	6.42E+00	3.22E+01	No
61	36	1	1	1	3	7.50E+00	3.91E-01	5.47E-03	7.38E-02	6.47E+00	3.22E+01	No
61	44	1	1	0	3	1.93E+01	3.92E-01	1.37E-03	3.70E-02	4.45E+00	3.22E+01	No
61	47	1	1	1	3	6.18E+00	3.92E-01	8.21E-03	9.03E-02	4.33E+00	3.22E+01	No
61	52	1	1	1	3	7.50E+00	3.95E-01	5.47E-03	7.38E-02	2.62E+00	3.22E+01	No
62	CW	2	2	-1	10		3.05E-01	4.24E-02	2.79E-01			Yes
62	2	1	1	1	4	8.40E+00	3.05E-01	2.74E-03	7.40E-02	3.12E+02	1.85E+03	Yes
62	4	1	1	1	4	5.79E+00	3.05E-01	5.47E-03	1.05E-01	2.45E+02	1.76E+03	Yes
62	5	1	1	1	4	5.79E+00	3.05E-01	9.58E-03	1.33E-01	2.60E+02	1.76E+03	Yes
62	27	1	1	1	3	8.40E+00	3.05E-01	2.74E-03	7.40E-02	8.98E+01	6.22E+02	No
62	37	1	1	0	3	1.49E+01	3.05E-01	1.37E-03	3.70E-02	8.52E+01	6.22E+02	No
62	41	1	1	1	3	5.79E+00	3.05E-01	5.47E-03	1.05E-01	5.27E+01	6.22E+02	No
62	42	1	1	1	3	5.79E+00	3.05E-01	9.58E-03	1.33E-01	6.63E+00	6.22E+02	No
62	45	1	1	1	3	8.40E+00	3.05E-01	2.74E-03	7.40E-02	1.61E+01	6.22E+02	No
62	46	1	1	0	3	1.49E+01	3.05E-01	1.37E-03	3.70E-02	3.10E+01	6.22E+02	No
62	51	1	1	0	3	1.49E+01	3.05E-01	1.37E-03	3.70E-02	4.19E+01	6.22E+02	No
63	CW	3	2	-1	10		1.69E-02	1.09E-02	1.47E-01			Yes
63	1	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	6.05E-01	3.03E+00	Yes
63	12	1	1	1	3	3.37E+00	1.69E-02	1.37E-03	3.70E-02	2.42E-01	1.07E+00	No
63	28	1	1	1	3	3.37E+00	1.69E-02	2.74E-03	5.23E-02	1.41E-01	1.07E+00	No
63	42	1	1	1	3	3.37E+00	1.69E-02	1.37E-03	3.70E-02	1.14E-02	1.07E+00	No
63	45	1	1	1	3	3.37E+00	1.69E-02	1.37E-03	3.70E-02	2.78E-02	1.07E+00	No
63	51	1	1	1	3	3.37E+00	1.69E-02	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
63	53	1	1	1	3	3.37E+00	1.69E-02	1.37E-03	3.70E-02	1.54E-01	1.07E+00	No
64	CW	2	2	-1	10		5.84E-01	3.83E-02	3.56E-01			Yes
64	1	1	1	0	4	1.89E+01	5.84E-01	1.37E-03	3.70E-02	3.17E+02	1.59E+03	Yes
64	13	1	1	1	3	9.14E+00	5.84E-01	6.84E-03	8.25E-02	1.28E+02	5.62E+02	No
64	25	1	1	1	3	9.14E+00	5.84E-01	5.47E-03	7.38E-02	1.83E+02	1.32E+03	No
64	26	1	1	1	3	1.11E+01	5.84E-01	4.10E-03	6.40E-02	2.02E+02	1.34E+03	No
64	38	1	1	1	3	1.11E+01	5.84E-01	2.74E-03	5.23E-02	9.69E+01	5.62E+02	No
64	40	1	1	1	3	9.14E+00	5.84E-01	5.47E-03	7.38E-02	5.25E+01	5.62E+02	No
64	47	1	1	0	3	1.89E+01	5.84E-01	1.37E-03	3.70E-02	7.55E+01	5.62E+02	No
64	51	1	1	1	3	9.14E+00	5.84E-01	6.84E-03	8.25E-02	3.79E+01	5.62E+02	No
64	52	1	1	0	3	1.89E+01	5.84E-01	1.37E-03	3.70E-02	4.57E+01	5.62E+02	No
64	53	1	1	1	3	1.11E+01	5.84E-01	2.74E-03	5.23E-02	8.08E+01	5.62E+02	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
65	CW	1	1	-1	10		2.13E+00	1.23E-02	2.10E-01			No
65	19	1	1	1	3	3.34E+01	2.13E+00	2.74E-03	5.23E-02	1.64E+02	6.58E+02	No
65	42	1	1	0	3	4.05E+01	2.13E+00	1.37E-03	3.70E-02	7.02E+00	6.58E+02	No
65	43	1	1	0	3	4.05E+01	2.13E+00	1.37E-03	3.70E-02	3.14E+01	6.58E+02	No
65	47	1	1	0	3	4.05E+01	2.13E+00	1.37E-03	3.70E-02	8.85E+01	6.58E+02	No
65	51	1	1	1	3	3.34E+01	2.13E+00	2.74E-03	5.23E-02	4.44E+01	6.58E+02	No
65	52	1	1	1	3	3.34E+01	2.13E+00	2.74E-03	5.23E-02	5.35E+01	6.58E+02	No
66	CW	6	2	-1	10		1.10E-02	2.74E-02	2.76E-01			No
66	25	1	1	1	3	2.18E+00	1.10E-02	1.37E-03	3.70E-02	3.48E+01	2.53E+02	No
66	27	1	1	2	3	2.18E+00	1.10E-02	2.74E-03	7.40E-02	1.55E+01	1.07E+02	No
66	31	1	1	2	3	2.18E+00	1.10E-02	2.74E-03	7.40E-02	2.65E+01	1.07E+02	No
66	34	1	1	1	3	2.18E+00	1.10E-02	1.37E-03	3.70E-02	1.56E+01	1.07E+02	No
66	35	1	1	1	3	2.18E+00	1.10E-02	1.37E-03	3.70E-02	3.38E+01	1.07E+02	No
66	42	1	1	2	3	2.18E+00	1.10E-02	2.74E-03	7.40E-02	1.14E+00	1.07E+02	No
66	43	1	1	2	3	2.18E+00	1.10E-02	2.74E-03	7.40E-02	5.12E+00	1.07E+02	No
66	45	2	1	1	3	2.18E+00	1.10E-02	5.47E-03	7.38E-02	2.78E+00	1.07E+02	No
66	46	1	1	2	3	2.18E+00	1.10E-02	2.74E-03	7.40E-02	5.35E+00	1.07E+02	No
66	53	1	1	2	3	2.18E+00	1.10E-02	4.10E-03	8.27E-02	1.54E+01	1.07E+02	No
67	CW	3	2	-1	15		1.28E-02	1.37E-02	1.48E-01			No
67	13	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	1.22E+00	5.36E+00	No
67	16	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	1.37E+00	5.36E+00	No
67	29	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	6.38E-01	5.36E+00	No
67	33	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	8.83E-01	5.36E+00	No
67	34	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	7.80E-01	5.36E+00	No
67	38	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	9.25E-01	5.36E+00	No
67	42	1	1	1	3	2.55E+00	1.28E-02	2.74E-03	5.23E-02	5.71E-02	5.36E+00	No
67	43	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	2.56E-01	5.36E+00	No
67	52	1	1	1	3	2.55E+00	1.28E-02	1.37E-03	3.70E-02	4.36E-01	5.36E+00	No
68	CW	4	2	-1	15		6.79E-02	3.68E-02	3.66E-01			No
68	16	1	1	1	3	1.35E+01	6.79E-02	1.37E-03	3.70E-02	1.09E+00	4.29E+00	No
68	41	1	1	1	3	1.35E+01	6.79E-02	1.37E-03	3.70E-02	3.63E-01	4.29E+00	No
68	42	1	1	1	3	4.46E+00	6.79E-02	4.10E-03	6.40E-02	4.57E-02	4.29E+00	No
68	45	1	1	1	3	1.35E+01	6.79E-02	1.37E-03	3.70E-02	1.11E-01	4.29E+00	No
68	51	2	1	5	3	1.63E+00	6.79E-02	2.86E-02	3.31E-01	2.89E-01	4.29E+00	No
69	CW	43	4	-3	15		1.74E-02	7.04E-01	2.71E+00			Yes
69	6	3	2	14	4	3.46E+00	1.74E-02	1.37E-02	3.70E-01	1.65E+01	1.63E+02	Yes
69	7	2	1	11	4	8.51E-01	1.74E-02	2.05E-02	4.57E-01	1.99E+01	1.67E+02	Yes
69	12	5	2	13	3	4.17E-01	1.74E-02	8.89E-02	9.37E-01	1.31E+01	5.79E+01	No
69	14	4	2	8	3	4.17E-01	1.74E-02	7.23E-02	6.75E-01	1.56E+01	5.79E+01	No
69	15	13	2	14	3	2.72E-01	1.74E-02	3.16E-01	1.81E+00	1.35E+01	5.79E+01	No
69	17	3	1	6	3	5.62E-01	1.74E-02	4.24E-02	4.50E-01	1.48E+01	5.79E+01	No
69	21	3	1	9	3	8.51E-01	1.74E-02	3.01E-02	4.24E-01	1.16E+01	5.79E+01	No
69	26	3	1	8	3	5.62E-01	1.74E-02	4.10E-02	4.95E-01	2.08E+01	1.39E+02	No
69	34	4	1	9	3	4.79E-01	1.74E-02	5.61E-02	6.42E-01	8.42E+00	5.79E+01	No
69	46	3	1	5	3	8.51E-01	1.74E-02	2.33E-02	3.15E-01	2.89E+00	5.79E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
70	CW	31	4	-7	15		1.06E-02	3.99E-01	1.50E+00			Yes
70	5	5	2	10	4	2.11E+00	1.06E-02	2.60E-02	3.71E-01	2.24E+00	1.51E+01	Yes
70	18	4	2	5	3	6.97E-01	1.06E-02	3.83E-02	3.49E-01	1.49E+00	5.36E+00	No
70	21	5	2	5	3	2.11E+00	1.06E-02	2.60E-02	2.73E-01	1.07E+00	5.36E+00	No
70	22	7	2	7	3	2.93E-01	1.06E-02	9.67E-02	6.42E-01	9.39E-01	5.36E+00	No
70	24	4	2	4	3	6.97E-01	1.06E-02	3.56E-02	2.80E-01	8.34E-01	5.36E+00	No
70	25	1	1	4	3	2.11E+00	1.06E-02	4.10E-03	1.11E-01	1.74E+00	1.26E+01	No
70	26	2	1	3	3	2.11E+00	1.06E-02	5.47E-03	1.05E-01	1.93E+00	1.28E+01	No
70	27	6	2	7	3	2.93E-01	1.06E-02	8.47E-02	6.06E-01	7.74E-01	5.36E+00	No
70	32	5	2	9	3	5.20E-01	1.06E-02	4.51E-02	5.20E-01	1.20E+00	5.36E+00	No
70	35	4	2	6	3	6.97E-01	1.06E-02	3.69E-02	3.77E-01	1.69E+00	5.36E+00	No
71	CW	4	2	-1	14		6.61E-02	3.42E-02	3.17E-01			Yes
71	6	1	1	1	4	4.34E+00	6.61E-02	4.10E-03	6.40E-02	1.53E+01	1.51E+02	Yes
71	7	1	1	1	4	1.32E+01	6.61E-02	2.74E-03	5.23E-02	1.84E+01	1.54E+02	Yes
71	17	1	1	1	3	3.24E+00	6.61E-02	6.84E-03	8.25E-02	1.37E+01	5.36E+01	No
71	18	1	1	1	3	1.32E+01	6.61E-02	2.74E-03	5.23E-02	1.49E+01	5.36E+01	No
71	23	1	1	1	3	1.32E+01	6.61E-02	2.74E-03	5.23E-02	9.05E+00	5.36E+01	No
71	28	1	1	1	3	1.32E+01	6.61E-02	1.37E-03	3.70E-02	7.07E+00	5.36E+01	No
71	38	1	1	1	3	1.32E+01	6.61E-02	1.37E-03	3.70E-02	9.25E+00	5.36E+01	No
71	40	1	1	1	3	1.32E+01	6.61E-02	2.74E-03	5.23E-02	5.01E+00	5.36E+01	No
71	45	1	1	1	3	1.32E+01	6.61E-02	1.37E-03	3.70E-02	1.39E+00	5.36E+01	No
71	51	1	1	1	3	3.24E+00	6.61E-02	8.21E-03	9.03E-02	3.61E+00	5.36E+01	No
72	CW	3	2	-1	14		5.82E-02	2.19E-02	2.29E-01			Yes
72	6	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	3.06E+01	3.03E+02	Yes
72	13	1	1	1	3	1.16E+01	5.82E-02	2.74E-03	5.23E-02	2.45E+01	1.07E+02	No
72	16	1	1	3	3	1.16E+01	5.82E-02	2.74E-03	7.40E-02	2.73E+01	1.07E+02	No
72	22	1	1	1	3	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.88E+01	1.07E+02	No
72	35	1	1	1	3	1.16E+01	5.82E-02	1.37E-03	3.70E-02	3.38E+01	1.07E+02	No
72	38	1	1	1	3	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.85E+01	1.07E+02	No
72	40	1	1	1	3	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.00E+01	1.07E+02	No
72	42	1	1	1	3	2.85E+00	5.82E-02	6.84E-03	8.25E-02	1.14E+00	1.07E+02	No
72	51	1	1	1	3	1.16E+01	5.82E-02	2.74E-03	5.23E-02	7.22E+00	1.07E+02	No
73	CW	3	2	-1	14		1.16E-01	1.92E-02	2.14E-01			Yes
73	5	1	1	1	4	7.61E+00	1.16E-01	2.74E-03	5.23E-02	2.33E+01	1.57E+02	Yes
73	6	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	1.59E+01	1.57E+02	Yes
73	13	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	1.27E+01	5.58E+01	No
73	19	1	1	1	3	5.68E+00	1.16E-01	4.10E-03	6.40E-02	1.39E+01	5.58E+01	No
73	37	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	7.64E+00	5.58E+01	No
73	39	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	9.30E+00	5.58E+01	No
73	43	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	2.66E+00	5.58E+01	No
73	46	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	2.78E+00	5.58E+01	No
73	50	1	1	1	3	7.61E+00	1.16E-01	2.74E-03	5.23E-02	1.00E+01	5.58E+01	No
73	52	1	1	1	3	2.31E+01	1.16E-01	1.37E-03	3.70E-02	4.53E+00	5.58E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
74	**CW**	**17**	2	0	14		2.32E-02	2.16E-01	2.11E+00			Yes
74	**1**	**3**	1	24	4	7.52E-01	2.32E-02	3.97E-02	9.64E-01	5.15E+00	2.57E+01	Yes
74	**3**	**2**	1	2	4	4.63E+00	2.32E-02	9.58E-03	1.11E-01	4.29E+00	2.57E+01	Yes
74	**6**	**2**	1	1	4	4.63E+00	2.32E-02	6.84E-03	8.25E-02	2.60E+00	2.57E+01	Yes
74	**12**	**1**	1	1	3	4.63E+00	2.32E-02	1.37E-03	3.70E-02	2.06E+00	9.11E+00	No
74	**22**	**1**	1	1	3	4.63E+00	2.32E-02	2.74E-03	5.23E-02	1.60E+00	9.11E+00	No
74	**24**	**4**	1	37	3	4.42E-01	2.32E-02	8.21E-02	1.59E+00	1.42E+00	9.11E+00	No
74	**26**	**2**	1	3	3	4.63E+00	2.32E-02	5.47E-03	1.17E-01	3.27E+00	2.18E+01	No
74	**28**	**3**	1	11	3	1.14E+00	2.32E-02	2.74E-02	5.23E-01	1.20E+00	9.11E+00	No
74	**42**	**3**	1	18	3	7.52E-01	2.32E-02	3.28E-02	7.45E-01	9.71E-02	9.11E+00	No
74	**53**	**2**	1	1	3	4.63E+00	2.32E-02	8.21E-03	9.03E-02	1.31E+00	9.11E+00	No
75	**CW**	**1**	1	-1	14		2.46E-02	2.74E-03	5.23E-02			Yes
75	**10**	**1**	1	1	4	4.89E+00	2.46E-02	1.37E-03	3.70E-02	3.18E+00	2.72E+01	Yes
75	**31**	**1**	1	1	3	4.89E+00	2.46E-02	1.37E-03	3.70E-02	2.39E+00	9.65E+00	No
76	**CW**	**5**	2	-1	10		9.92E-03	2.46E-02	3.58E-01			No
76	**42**	**2**	1	7	3	1.97E+00	9.92E-03	6.84E-03	1.85E-01	8.00E-03	7.51E-01	No
76	**43**	**4**	2	7	3	1.97E+00	9.92E-03	1.78E-02	2.84E-01	3.58E-02	7.51E-01	No
77	**CW**	**2**	2	-1	10		7.77E-02	8.21E-03	1.37E-01			Yes
77	**5**	**1**	1	1	4	1.55E+01	7.77E-02	1.37E-03	3.70E-02	9.04E+00	6.11E+01	Yes
77	**14**	**1**	1	1	3	1.55E+01	7.77E-02	1.37E-03	3.70E-02	5.82E+00	2.17E+01	No
77	**17**	**1**	1	1	3	1.55E+01	7.77E-02	1.37E-03	3.70E-02	5.55E+00	2.17E+01	No
77	**40**	**1**	1	1	3	1.55E+01	7.77E-02	2.74E-03	5.23E-02	2.02E+00	2.17E+01	No
77	**46**	**1**	1	1	3	1.55E+01	7.77E-02	1.37E-03	3.70E-02	1.08E+00	2.17E+01	No
78	**CW**	**6**	2	-1	12		9.21E-04	2.60E-02	2.48E-01			Yes
78	**4**	**1**	1	4	4	1.83E-01	9.21E-04	4.10E-03	1.11E-01	2.11E-01	1.51E+00	Yes
78	**9**	**1**	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	2.14E-01	1.56E+00	Yes
78	**12**	**1**	1	2	3	1.83E-01	9.21E-04	4.10E-03	8.27E-02	1.21E-01	5.36E-01	No
78	**13**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.22E-01	5.36E-01	No
78	**14**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.44E-01	5.36E-01	No
78	**16**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.37E-01	5.36E-01	No
78	**21**	**2**	1	5	3	1.83E-01	9.21E-04	5.47E-03	1.48E-01	1.07E-01	5.36E-01	No
78	**26**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.93E-01	1.28E+00	No
78	**35**	**1**	1	4	3	1.83E-01	9.21E-04	4.10E-03	1.11E-01	1.69E-01	5.36E-01	No
78	**53**	**1**	1	1	3	1.83E-01	9.21E-04	1.37E-03	3.70E-02	7.71E-02	5.36E-01	No
79	**CW**	**3**	2	-1	12		1.21E-02	1.50E-02	1.43E-01			Yes
79	**1**	**1**	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	1.27E+00	6.36E+00	Yes
79	**6**	**1**	1	3	4	2.40E+00	1.21E-02	2.74E-03	7.40E-02	6.43E-01	6.36E+00	Yes
79	**10**	**1**	1	3	4	2.40E+00	1.21E-02	2.74E-03	7.40E-02	7.43E-01	6.36E+00	Yes
79	**11**	**1**	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	1.39E+00	6.64E+00	Yes
79	**13**	**1**	1	1	3	2.40E+00	1.21E-02	1.37E-03	3.70E-02	5.13E-01	2.25E+00	No
79	**21**	**1**	1	1	3	2.40E+00	1.21E-02	1.37E-03	3.70E-02	4.50E-01	2.25E+00	No
79	**30**	**1**	1	1	3	2.40E+00	1.21E-02	1.37E-03	3.70E-02	6.01E-01	2.25E+00	No
79	**32**	**1**	1	1	3	2.40E+00	1.21E-02	1.37E-03	3.70E-02	5.04E-01	2.25E+00	No
79	**53**	**1**	1	1	3	2.40E+00	1.21E-02	1.37E-03	3.70E-02	3.24E-01	2.25E+00	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
80	CW	17	3	-8	8		3.07E-02	2.39E-01	9.51E-01			Yes
80	4	2	1	1	4	6.12E+00	3.07E-02	6.84E-03	8.25E-02	3.13E+01	2.24E+02	Yes
80	7	2	1	1	4	2.02E+00	3.07E-02	1.09E-02	1.04E-01	2.73E+01	2.28E+02	Yes
80	18	3	1	2	3	8.48E-01	3.07E-02	3.69E-02	1.89E-01	2.20E+01	7.93E+01	No
80	22	3	1	2	3	8.48E-01	3.07E-02	3.97E-02	2.22E-01	1.39E+01	7.93E+01	No
80	25	3	1	2	3	8.48E-01	3.07E-02	3.42E-02	1.96E-01	2.58E+01	1.87E+02	No
80	33	2	1	2	3	2.02E+00	3.07E-02	1.92E-02	1.47E-01	1.31E+01	7.93E+01	No
80	35	3	1	2	3	8.48E-01	3.07E-02	3.28E-02	2.00E-01	2.50E+01	7.93E+01	No
80	40	2	1	1	3	2.02E+00	3.07E-02	1.23E-02	1.10E-01	7.41E+00	7.93E+01	No
80	50	2	1	1	3	2.02E+00	3.07E-02	1.50E-02	1.22E-01	1.42E+01	7.93E+01	No
80	52	3	1	1	3	8.48E-01	3.07E-02	3.15E-02	1.75E-01	6.45E+00	7.93E+01	No
81	CW	2	2	-1	8		9.49E-02	1.92E-02	2.60E-01			No
81	15	1	1	1	3	6.23E+00	9.49E-02	2.74E-03	5.23E-02	8.24E+00	3.53E+01	No
81	22	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	6.18E+00	3.53E+01	No
81	25	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	1.15E+01	8.31E+01	No
81	27	1	1	1	3	6.23E+00	9.49E-02	2.74E-03	5.23E-02	5.09E+00	3.53E+01	No
81	38	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	6.08E+00	3.53E+01	No
81	39	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	5.89E+00	3.53E+01	No
81	42	1	1	1	3	6.23E+00	9.49E-02	2.74E-03	5.23E-02	3.76E-01	3.53E+01	No
81	45	1	1	1	3	6.23E+00	9.49E-02	2.74E-03	5.23E-02	9.15E-01	3.53E+01	No
81	46	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	1.76E+00	3.53E+01	No
81	49	1	1	1	3	1.89E+01	9.49E-02	1.37E-03	3.70E-02	5.34E+00	3.53E+01	No
82	CW	2	2	-1	14		1.04E-01	1.23E-02	1.62E-01			Yes
82	10	1	1	1	4	6.82E+00	1.04E-01	2.74E-03	5.23E-02	5.64E+01	4.83E+02	Yes
82	28	1	1	2	3	6.82E+00	1.04E-01	2.74E-03	7.40E-02	2.26E+01	1.71E+02	No
82	40	1	1	1	3	2.07E+01	1.04E-01	1.37E-03	3.70E-02	1.60E+01	1.71E+02	No
82	42	1	1	2	3	6.82E+00	1.04E-01	2.74E-03	7.40E-02	1.82E+00	1.71E+02	No
82	49	1	1	1	3	2.07E+01	1.04E-01	1.37E-03	3.70E-02	2.59E+01	1.71E+02	No
82	50	1	1	1	3	2.07E+01	1.04E-01	1.37E-03	3.70E-02	3.07E+01	1.71E+02	No
83	CW	3	2	-1	10		1.96E-01	4.24E-02	3.88E-01			No
83	13	1	1	1	3	9.63E+00	1.96E-01	2.74E-03	5.23E-02	4.77E+00	2.09E+01	No
83	20	1	1	1	3	9.63E+00	1.96E-01	2.74E-03	5.23E-02	6.09E+00	2.09E+01	No
83	24	1	1	1	3	5.42E+00	1.96E-01	5.47E-03	7.38E-02	3.25E+00	2.09E+01	No
83	25	1	1	1	3	6.35E+00	1.96E-01	4.10E-03	6.40E-02	6.79E+00	4.93E+01	No
83	27	1	1	0	3	1.29E+01	1.96E-01	1.37E-03	3.70E-02	3.02E+00	2.09E+01	No
83	43	1	1	1	3	3.73E+00	1.96E-01	1.23E-02	1.10E-01	9.98E-01	2.09E+01	No
83	45	1	1	1	3	9.63E+00	1.96E-01	2.74E-03	5.23E-02	5.42E-01	2.09E+01	No
83	48	1	1	1	3	6.35E+00	1.96E-01	4.10E-03	6.40E-02	2.77E+00	2.09E+01	No
83	49	1	1	1	3	6.35E+00	1.96E-01	4.10E-03	6.40E-02	3.17E+00	2.09E+01	No
83	53	1	1	1	3	9.63E+00	1.96E-01	2.74E-03	5.23E-02	3.01E+00	2.09E+01	No
84	CW	1	1	-1	8		5.15E-02	2.74E-03	1.22E-01			No
84	44	1	1	1	3	1.02E+01	5.15E-02	2.74E-03	5.23E-02	8.42E+00	6.09E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
85	**CW**	**8**	2	-2	6		6.23E-03	4.10E-02	4.63E-01			Yes
85	**3**	**2**	2	9	4	1.24E+00	6.23E-03	8.21E-03	2.22E-01	1.31E+00	7.87E+00	Yes
85	**14**	**1**	1	3	3	1.24E+00	6.23E-03	2.74E-03	7.40E-02	7.49E-01	2.79E+00	No
85	**31**	**1**	1	3	3	1.24E+00	6.23E-03	2.74E-03	7.40E-02	6.90E-01	2.79E+00	No
85	**32**	**1**	1	3	3	1.24E+00	6.23E-03	2.74E-03	7.40E-02	6.24E-01	2.79E+00	No
85	**39**	**1**	1	1	3	1.24E+00	6.23E-03	2.74E-03	5.23E-02	4.65E-01	2.79E+00	No
85	**49**	**2**	1	5	3	1.24E+00	6.23E-03	5.47E-03	1.48E-01	4.22E-01	2.79E+00	No
85	**50**	**4**	2	10	3	1.24E+00	6.23E-03	1.64E-02	3.31E-01	5.00E-01	2.79E+00	No
86	**CW**	**2**	2	-1	6		4.41E-02	8.21E-03	1.59E-01			No
86	**21**	**1**	1	2	3	8.78E+00	4.41E-02	4.10E-03	8.27E-02	2.23E+00	1.12E+01	No
86	**22**	**1**	1	1	3	8.78E+00	4.41E-02	1.37E-03	3.70E-02	1.95E+00	1.12E+01	No
86	**47**	**1**	1	1	3	8.78E+00	4.41E-02	2.74E-03	5.23E-02	1.50E+00	1.12E+01	No
87	**CW**	**7**	2	-2	10		5.55E-03	3.15E-02	3.15E-01			Yes
87	**4**	**1**	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.69E-01	1.21E+00	Yes
87	**5**	**1**	1	3	4	1.10E+00	5.55E-03	2.74E-03	7.40E-02	1.79E-01	1.21E+00	Yes
87	**8**	**3**	2	6	4	1.10E+00	5.55E-03	1.23E-02	2.12E-01	1.36E-01	1.23E+00	Yes
87	**13**	**1**	1	1	3	1.10E+00	5.55E-03	2.74E-03	5.23E-02	9.78E-02	4.29E-01	No
87	**16**	**1**	1	1	3	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.09E-01	4.29E-01	No
87	**19**	**1**	1	1	3	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.07E-01	4.29E-01	No
87	**25**	**1**	1	3	3	1.10E+00	5.55E-03	4.10E-03	8.27E-02	1.39E-01	1.01E+00	No
87	**32**	**1**	1	1	3	1.10E+00	5.55E-03	1.37E-03	3.70E-02	9.59E-02	4.29E-01	No
87	**33**	**1**	1	1	3	1.10E+00	5.55E-03	2.74E-03	5.23E-02	7.06E-02	4.29E-01	No
87	**53**	**1**	1	1	3	1.10E+00	5.55E-03	1.37E-03	3.70E-02	6.16E-02	4.29E-01	No
88	**CW**	**4**	2	-1	10		2.57E-02	1.78E-02	2.37E-01			Yes
88	**6**	**1**	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.66E+01	1.64E+02	Yes
88	**9**	**1**	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	2.32E+01	1.70E+02	Yes
88	**10**	**1**	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.92E+01	1.64E+02	Yes
88	**19**	**1**	1	1	3	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.45E+01	5.81E+01	No
88	**31**	**1**	1	1	3	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.44E+01	5.81E+01	No
88	**47**	**1**	1	1	3	5.12E+00	2.57E-02	1.37E-03	3.70E-02	7.81E+00	5.81E+01	No
88	**52**	**2**	1	1	3	5.12E+00	2.57E-02	8.21E-03	9.03E-02	4.73E+00	5.81E+01	No
88	**53**	**1**	1	1	3	5.12E+00	2.57E-02	1.37E-03	3.70E-02	8.35E+00	5.81E+01	No
89	**CW**	**9**	2	-2	10		1.91E-03	4.24E-02	2.91E-01			Yes
89	**11**	**1**	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	1.33E-01	6.32E-01	Yes
89	**13**	**2**	1	3	3	3.81E-01	1.91E-03	5.47E-03	1.05E-01	4.89E-02	2.14E-01	No
89	**25**	**1**	1	3	3	3.81E-01	1.91E-03	2.74E-03	7.40E-02	6.97E-02	5.05E-01	No
89	**29**	**2**	1	3	3	3.81E-01	1.91E-03	8.21E-03	1.28E-01	2.55E-02	2.14E-01	No
89	**31**	**1**	1	3	3	3.81E-01	1.91E-03	2.74E-03	7.40E-02	5.31E-02	2.14E-01	No
89	**37**	**1**	1	3	3	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.94E-02	2.14E-01	No
89	**42**	**1**	1	3	3	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.29E-03	2.14E-01	No
89	**47**	**1**	1	3	3	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.88E-02	2.14E-01	No
89	**48**	**2**	1	3	3	3.81E-01	1.91E-03	6.84E-03	1.11E-01	2.84E-02	2.14E-01	No
89	**53**	**2**	1	3	3	3.81E-01	1.91E-03	5.47E-03	1.05E-01	3.08E-02	2.14E-01	No
90	**CW**	**1**	1	-1	10		6.60E-03	1.37E-03	3.70E-02			No
90	**43**	**1**	1	1	3	1.31E+00	6.60E-03	1.37E-03	3.70E-02	6.30E+00	1.32E+02	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
91	CW	7	2	-2	10		2.01E-02	3.15E-02	3.91E-01			Yes
91	6	2	1	1	4	4.01E+00	2.01E-02	5.47E-03	7.38E-02	8.57E-01	8.47E+00	Yes
91	9	1	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	1.20E+00	8.76E+00	Yes
91	16	3	1	1	3	4.01E+00	2.01E-02	1.37E-02	1.16E-01	7.65E-01	3.00E+00	No
91	17	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	7.69E-01	3.00E+00	No
91	18	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	8.34E-01	3.00E+00	No
91	24	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	4.67E-01	3.00E+00	No
91	25	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	9.75E-01	7.07E+00	No
91	34	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	4.37E-01	3.00E+00	No
91	45	1	1	1	3	4.01E+00	2.01E-02	2.74E-03	5.23E-02	7.79E-02	3.00E+00	No
91	51	1	1	1	3	4.01E+00	2.01E-02	1.37E-03	3.70E-02	2.02E-01	3.00E+00	No
92	CW	1	2	-1	10		3.42E-02	4.10E-03	1.21E-01			No
92	24	1	1	1	3	6.80E+00	3.42E-02	1.37E-03	3.70E-02	4.34E+00	2.79E+01	No
92	53	1	1	1	3	6.80E+00	3.42E-02	2.74E-03	5.23E-02	4.01E+00	2.79E+01	No
93	CW	20	3	-9	10		3.54E-02	3.42E-01	1.05E+00			Yes
93	4	3	1	2	4	8.50E-01	3.54E-02	4.65E-02	2.11E-01	1.69E+01	1.21E+02	Yes
93	5	4	1	2	4	6.73E-01	3.54E-02	6.16E-02	2.57E-01	1.79E+01	1.21E+02	Yes
93	8	3	1	2	4	9.77E-01	3.54E-02	3.69E-02	1.89E-01	1.36E+01	1.23E+02	Yes
93	12	3	1	2	3	9.77E-01	3.54E-02	3.97E-02	2.09E-01	9.70E+00	4.29E+01	No
93	16	3	1	2	3	9.77E-01	3.54E-02	3.28E-02	1.86E-01	1.09E+01	4.29E+01	No
93	18	2	1	2	3	1.74E+00	3.54E-02	1.50E-02	1.33E-01	1.19E+01	4.29E+01	No
93	20	3	1	1	3	9.77E-01	3.54E-02	3.56E-02	1.85E-01	1.25E+01	4.29E+01	No
93	23	3	1	2	3	9.77E-01	3.54E-02	3.28E-02	1.86E-01	7.24E+00	4.29E+01	No
93	34	3	1	2	3	9.77E-01	3.53E-02	3.42E-02	1.89E-01	6.24E+00	4.29E+01	No
93	38	1	1	2	3	2.33E+00	3.53E-02	6.84E-03	9.77E-02	7.40E+00	4.29E+01	No
94	CW	18	3	1	15		3.90E-02	2.90E-01	1.66E+00			Yes
94	10	4	1	10	4	7.42E-01	3.90E-02	7.50E-02	8.09E-01	4.95E+00	4.24E+01	Yes
94	13	2	1	5	3	1.91E+00	3.90E-02	1.37E-02	2.67E-01	3.42E+00	1.50E+01	No
94	15	3	1	14	3	7.42E-01	3.90E-02	4.38E-02	8.38E-01	3.51E+00	1.50E+01	No
94	18	2	1	11	3	9.37E-01	3.90E-02	3.96E-02	5.65E-01	4.17E+00	1.50E+01	No
94	19	2	1	11	3	1.91E+00	3.90E-02	1.64E-02	4.44E-01	3.74E+00	1.50E+01	No
94	22	2	1	7	3	1.91E+00	3.90E-02	1.64E-02	3.31E-01	2.63E+00	1.50E+01	No
94	31	2	1	9	3	1.91E+00	3.90E-02	1.37E-02	3.70E-01	3.71E+00	1.50E+01	No
94	35	3	1	8	3	7.42E-01	3.90E-02	4.37E-02	5.86E-01	4.73E+00	1.50E+01	No
94	49	2	1	7	3	1.26E+00	3.90E-02	2.19E-02	4.18E-01	2.27E+00	1.50E+01	No
94	51	2	1	5	3	7.77E+00	3.90E-02	5.47E-03	1.48E-01	1.01E+00	1.50E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
95	CW	31	3	-3	15		5.54E-03	2.91E-01	2.22E+00			No
95	14	7	2	26	3	2.71E-01	5.54E-03	7.39E-02	1.31E+00	1.44E+00	5.36E+00	No
95	17	2	1	7	3	1.10E+00	5.54E-03	6.84E-03	1.85E-01	1.37E+00	5.36E+00	No
95	24	6	2	24	3	2.71E-01	5.54E-03	6.16E-02	1.09E+00	8.34E-01	5.36E+00	No
95	27	8	2	17	3	1.10E+00	5.54E-03	3.97E-02	6.45E-01	7.74E-01	5.36E+00	No
95	29	2	1	5	3	1.10E+00	5.54E-03	5.47E-03	1.48E-01	6.38E-01	5.36E+00	No
95	35	9	2	19	3	1.10E+00	5.54E-03	4.79E-02	7.62E-01	1.69E+00	5.36E+00	No
95	37	3	2	7	3	1.10E+00	5.54E-03	1.50E-02	2.48E-01	7.35E-01	5.36E+00	No
95	45	6	2	29	3	1.10E+00	5.54E-03	2.74E-02	7.40E-01	1.39E-01	5.36E+00	No
95	48	3	2	15	3	1.10E+00	5.54E-03	1.37E-02	3.70E-01	7.11E-01	5.36E+00	No
96	CW	12	3	-3	10		1.37E-01	3.21E-01	9.54E-01			Yes
96	5	2	1	1	4	2.10E+00	1.34E-01	4.92E-02	2.23E-01	2.06E+01	1.40E+02	Yes
96	9	2	1	1	4	2.55E+00	1.34E-01	2.19E-02	1.46E-01	1.97E+01	1.44E+02	Yes
96	10	2	1	1	4	2.55E+00	1.34E-01	2.74E-02	1.63E-01	1.63E+01	1.40E+02	Yes
96	14	1	1	1	3	3.70E+00	1.34E-01	6.84E-03	8.25E-02	1.33E+01	4.94E+01	No
96	20	1	1	1	3	3.22E+00	1.38E-01	8.21E-03	9.03E-02	1.44E+01	4.94E+01	No
96	26	2	1	1	3	2.55E+00	1.34E-01	2.87E-02	1.67E-01	1.78E+01	1.18E+02	No
96	27	3	1	1	3	2.10E+00	1.36E-01	5.19E-02	2.28E-01	7.13E+00	4.94E+01	No
96	34	2	1	1	3	2.10E+00	1.36E-01	3.28E-02	1.86E-01	7.19E+00	4.94E+01	No
96	42	4	1	1	3	2.10E+00	1.52E-01	8.21E-02	2.80E-01	5.27E-01	4.94E+01	No
96	50	1	1	1	3	3.22E+00	1.34E-01	1.23E-02	1.22E-01	8.87E+00	4.94E+01	No
97	CW	3	2	-1	10		2.26E-03	1.50E-02	1.73E-01			No
97	19	2	1	2	3	4.50E-01	2.26E-03	6.84E-03	1.11E-01	2.67E-01	1.07E+00	No
97	21	1	1	3	3	4.50E-01	2.26E-03	2.74E-03	7.40E-02	2.14E-01	1.07E+00	No
97	22	1	1	3	3	4.50E-01	2.26E-03	2.74E-03	7.40E-02	1.88E-01	1.07E+00	No
97	52	1	1	3	3	4.50E-01	2.26E-03	2.74E-03	7.40E-02	8.72E-02	1.07E+00	No
98	CW	4	2	-2	10		9.52E-02	3.01E-02	3.32E-01			Yes
98	1	1	1	1	4	1.90E+01	9.52E-02	1.37E-03	3.70E-02	1.09E+01	5.45E+01	Yes
98	2	1	1	1	4	1.90E+01	9.52E-02	1.37E-03	3.70E-02	9.69E+00	5.75E+01	Yes
98	3	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	9.08E+00	5.45E+01	Yes
98	4	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	7.61E+00	5.45E+01	Yes
98	10	1	1	1	4	3.08E+00	9.52E-02	8.21E-03	9.03E-02	6.36E+00	5.45E+01	Yes
98	16	1	1	1	3	6.25E+00	9.52E-02	2.74E-03	5.23E-02	4.92E+00	1.93E+01	No
98	18	1	1	1	3	4.67E+00	9.52E-02	4.10E-03	6.40E-02	5.36E+00	1.93E+01	No
98	20	1	1	1	3	6.25E+00	9.52E-02	2.74E-03	5.23E-02	5.62E+00	1.93E+01	No
98	27	1	1	1	3	1.90E+01	9.52E-02	1.37E-03	3.70E-02	2.79E+00	1.93E+01	No
98	36	1	1	1	3	6.25E+00	9.52E-02	2.74E-03	5.23E-02	3.88E+00	1.93E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
99	CW	25	2	-4	10		2.66E-04	1.27E-01	1.12E+00			No
99	15	4	2	9	3	5.30E-02	2.66E-04	1.92E-02	3.18E-01	2.51E-01	1.07E+00	No
99	20	1	1	3	3	5.30E-02	2.66E-04	2.74E-03	7.40E-02	3.12E-01	1.07E+00	No
99	29	6	2	27	3	5.30E-02	2.66E-04	3.01E-02	7.43E-01	1.28E-01	1.07E+00	No
99	31	3	2	7	3	5.30E-02	2.66E-04	1.37E-02	2.61E-01	2.65E-01	1.07E+00	No
99	33	2	1	7	3	5.30E-02	2.66E-04	6.84E-03	1.85E-01	1.77E-01	1.07E+00	No
99	34	3	2	11	3	5.30E-02	2.66E-04	1.09E-02	2.96E-01	1.56E-01	1.07E+00	No
99	37	2	1	3	3	5.30E-02	2.66E-04	5.47E-03	1.05E-01	1.47E-01	1.07E+00	No
99	42	2	1	7	3	5.30E-02	2.66E-04	6.84E-03	1.85E-01	1.14E-02	1.07E+00	No
99	46	1	1	1	3	5.30E-02	2.66E-04	1.37E-03	3.70E-02	5.35E-02	1.07E+00	No
99	47	6	2	15	3	5.30E-02	2.66E-04	3.01E-02	5.25E-01	1.44E-01	1.07E+00	No
100	CW	5	2	-2	10		4.41E-03	2.19E-02	2.93E-01			Yes
100	6	2	1	1	4	8.77E-01	4.41E-03	5.47E-03	7.38E-02	3.06E-01	3.03E+00	Yes
100	8	1	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	3.41E-01	3.08E+00	Yes
100	13	1	1	1	3	8.77E-01	4.41E-03	2.74E-03	5.23E-02	2.45E-01	1.07E+00	No
100	22	1	1	1	3	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.88E-01	1.07E+00	No
100	24	1	1	1	3	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.67E-01	1.07E+00	No
100	25	1	1	1	3	8.77E-01	4.41E-03	2.74E-03	5.23E-02	3.48E-01	2.53E+00	No
100	26	1	1	1	3	8.77E-01	4.41E-03	1.37E-03	3.70E-02	3.85E-01	2.57E+00	No
100	37	1	1	1	3	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
100	52	1	1	1	3	8.77E-01	4.41E-03	1.37E-03	3.70E-02	8.72E-02	1.07E+00	No
100	53	1	1	1	3	8.77E-01	4.41E-03	2.74E-03	5.23E-02	1.54E-01	1.07E+00	No
101	CW	4	2	-1	10		3.38E-03	1.78E-02	2.01E-01			Yes
101	4	1	1	1	4	6.73E-01	3.38E-03	2.74E-03	5.23E-02	4.23E-02	3.03E-01	Yes
101	6	1	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	3.06E-02	3.03E-01	Yes
101	9	1	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	4.27E-02	3.13E-01	Yes
101	13	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.45E-02	1.07E-01	No
101	15	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.51E-02	1.07E-01	No
101	32	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.40E-02	1.07E-01	No
101	38	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.85E-02	1.07E-01	No
101	44	1	1	1	3	6.73E-01	3.38E-03	4.10E-03	6.40E-02	1.48E-02	1.07E-01	No
101	49	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.62E-02	1.07E-01	No
101	50	1	1	1	3	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.92E-02	1.07E-01	No
102	CW	3	2	-1	10		2.55E-02	1.50E-02	1.69E-01			Yes
102	5	2	1	3	4	5.08E+00	2.55E-02	5.47E-03	1.05E-01	8.91E+00	6.02E+01	Yes
102	7	1	1	3	4	5.08E+00	2.55E-02	2.74E-03	7.40E-02	7.34E+00	6.14E+01	Yes
102	11	1	1	3	4	5.08E+00	2.55E-02	2.74E-03	7.40E-02	1.32E+01	6.29E+01	Yes
102	31	1	1	1	3	5.08E+00	2.55E-02	1.37E-03	3.70E-02	5.28E+00	2.13E+01	No
102	50	1	1	3	3	5.08E+00	2.55E-02	2.74E-03	7.40E-02	3.83E+00	2.13E+01	No

Appendix I

Item nbr	WH Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
103	**CW**	**3**	2	-1	10		4.46E-02	1.37E-02	1.17E-01			Yes
103	**1**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	2.00E+01	9.99E+01	Yes
103	**2**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.78E+01	1.05E+02	Yes
103	**6**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.01E+01	9.99E+01	Yes
103	**7**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.22E+01	1.02E+02	Yes
103	**11**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	2.19E+01	1.04E+02	Yes
103	**20**	**1**	1	1	3	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.03E+01	3.54E+01	No
103	**25**	**1**	1	1	3	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.15E+01	8.34E+01	No
103	**30**	**1**	1	1	3	8.87E+00	4.46E-02	1.37E-03	3.70E-02	9.45E+00	3.54E+01	No
103	**31**	**1**	1	1	3	8.87E+00	4.46E-02	1.37E-03	3.70E-02	8.75E+00	3.54E+01	No
103	**40**	**1**	1	1	3	8.87E+00	4.46E-02	1.37E-03	3.70E-02	3.30E+00	3.54E+01	No
104	**CW**	**4**	2	-1	10		4.67E-02	3.15E-02	3.09E-01			Yes
104	**4**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	9.72E+00	6.96E+01	Yes
104	**7**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	8.48E+00	7.10E+01	Yes
104	**9**	**1**	1	1	4	9.30E+00	4.67E-02	1.37E-03	3.70E-02	9.83E+00	7.19E+01	Yes
104	**10**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	8.13E+00	6.96E+01	Yes
104	**24**	**1**	1	1	3	9.30E+00	4.67E-02	1.37E-03	3.70E-02	3.84E+00	2.47E+01	No
104	**43**	**1**	1	2	3	2.29E+00	4.67E-02	9.58E-03	1.33E-01	1.18E+00	2.47E+01	No
104	**46**	**1**	1	1	3	9.30E+00	4.67E-02	1.37E-03	3.70E-02	1.23E+00	2.47E+01	No
104	**50**	**1**	1	1	3	9.30E+00	4.67E-02	2.74E-03	5.23E-02	4.42E+00	2.47E+01	No
104	**51**	**1**	1	2	3	9.30E+00	4.67E-02	4.10E-03	8.26E-02	1.66E+00	2.47E+01	No
104	**52**	**1**	1	1	3	9.30E+00	4.67E-02	2.74E-03	5.23E-02	2.01E+00	2.47E+01	No
105	**CW**	**5**	2	-2	10		2.19E-02	2.19E-02	2.80E-01			Yes
105	**1**	**1**	1	3	4	4.35E+00	2.19E-02	2.74E-03	7.40E-02	6.05E-01	3.03E+00	Yes
105	**8**	**2**	1	1	4	4.35E+00	2.19E-02	5.47E-03	7.38E-02	3.41E-01	3.08E+00	Yes
105	**13**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.45E-01	1.07E+00	No
105	**17**	**1**	1	1	3	4.35E+00	2.19E-02	2.74E-03	5.23E-02	2.75E-01	1.07E+00	No
105	**19**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.67E-01	1.07E+00	No
105	**23**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	1.81E-01	1.07E+00	No
105	**30**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.86E-01	1.07E+00	No
105	**34**	**1**	1	1	3	4.35E+00	2.19E-02	2.74E-03	5.23E-02	1.56E-01	1.07E+00	No
105	**37**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
105	**43**	**1**	1	1	3	4.35E+00	2.19E-02	1.37E-03	3.70E-02	5.12E-02	1.07E+00	No
106	**CW**	**2**	2	-1	10		4.59E-03	9.58E-03	1.51E-01			No
106	**12**	**1**	1	3	3	9.13E-01	4.59E-03	2.74E-03	7.40E-02	2.42E-01	1.07E+00	No
106	**27**	**1**	1	1	3	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.55E-01	1.07E+00	No
106	**29**	**1**	1	1	3	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.28E-01	1.07E+00	No
106	**42**	**1**	1	1	3	9.13E-01	4.59E-03	2.74E-03	5.23E-02	1.14E-02	1.07E+00	No
106	**47**	**1**	1	1	3	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.44E-01	1.07E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
1	**CW**	**2**	2	-1	8		1.09E-02	5.47E-03	1.33E-01			No
1	**14**	**1**	1	1	4	2.17E+00	1.09E-02	1.37E-03	3.70E-02	2.02E+00	7.51E+00	No
1	**35**	**1**	1	1	4	2.17E+00	1.09E-02	1.37E-03	3.70E-02	2.36E+00	7.51E+00	No
1	**42**	**1**	1	1	4	2.17E+00	1.09E-02	2.74E-03	5.23E-02	8.00E-02	7.51E+00	No
2	**CW**	**3**	2	-1	8		6.13E-02	2.33E-02	2.09E-01			No
2	**12**	**1**	1	3	4	1.22E+01	6.13E-02	2.74E-03	7.40E-02	7.51E-01	3.32E+00	No
2	**14**	**1**	1	1	4	1.22E+01	6.13E-02	2.74E-03	5.23E-02	8.93E-01	3.32E+00	No
2	**17**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.51E-01	3.32E+00	No
2	**22**	**1**	1	1	4	4.03E+00	6.13E-02	4.10E-03	8.27E-02	5.82E-01	3.32E+00	No
2	**26**	**1**	1	1	4	3.00E+00	6.13E-02	5.47E-03	9.05E-02	1.19E+00	7.95E+00	No
2	**30**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.88E-01	3.32E+00	No
2	**31**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	8.22E-01	3.32E+00	No
2	**37**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	4.55E-01	3.32E+00	No
2	**42**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	3.54E-02	3.32E+00	No
2	**53**	**1**	1	1	4	1.22E+01	6.13E-02	1.37E-03	3.70E-02	4.78E-01	3.32E+00	No
3	**CW**	**2**	2	-1	8		6.92E-02	1.64E-02	1.77E-01			No
3	**15**	**1**	1	3	4	1.38E+01	6.92E-02	2.74E-03	7.40E-02	1.10E+00	4.72E+00	No
3	**19**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.18E+00	4.72E+00	No
3	**25**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.53E+00	1.11E+01	No
3	**26**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	1.69E+00	1.13E+01	No
3	**31**	**1**	1	1	4	1.38E+01	6.92E-02	2.74E-03	5.23E-02	1.17E+00	4.72E+00	No
3	**37**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.46E-01	4.72E+00	No
3	**40**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	4.41E-01	4.72E+00	No
3	**46**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	2.36E-01	4.72E+00	No
3	**48**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.26E-01	4.72E+00	No
3	**53**	**1**	1	1	4	1.38E+01	6.92E-02	1.37E-03	3.70E-02	6.78E-01	4.72E+00	No
4	**CW**	**3**	2	-1	8		3.88E-02	1.09E-02	2.17E-01			No
4	**17**	**1**	1	1	4	7.73E+00	3.88E-02	2.74E-03	5.23E-02	4.61E+00	1.80E+01	No
4	**32**	**1**	1	1	4	7.73E+00	3.88E-02	2.74E-03	5.23E-02	4.03E+00	1.80E+01	No
4	**44**	**1**	1	1	4	7.73E+00	3.88E-02	1.37E-03	3.70E-02	2.49E+00	1.80E+01	No
4	**46**	**1**	1	1	4	7.73E+00	3.88E-02	1.37E-03	3.70E-02	8.99E-01	1.80E+01	No
4	**52**	**1**	1	1	4	7.73E+00	3.88E-02	2.74E-03	5.23E-02	1.47E+00	1.80E+01	No
5	**CW**	**8**	2	-1	8		4.67E-02	1.11E-01	9.04E-01			No
5	**14**	**2**	1	5	4	1.12E+00	4.67E-02	3.69E-02	3.88E-01	7.81E+02	2.91E+03	No
5	**27**	**2**	1	13	4	1.12E+00	4.67E-02	3.56E-02	5.77E-01	4.20E+02	2.91E+03	No
5	**33**	**1**	1	3	4	3.07E+00	4.67E-02	5.47E-03	1.48E-01	4.79E+02	2.91E+03	No
5	**34**	**2**	1	9	4	1.29E+00	4.67E-02	2.74E-02	5.23E-01	4.23E+02	2.91E+03	No
5	**48**	**1**	1	3	4	3.07E+00	4.67E-02	5.47E-03	1.48E-01	3.85E+02	2.91E+03	No
6	**CW**	**5**	2	-1	8		4.85E-02	2.19E-02	2.67E-01			No
6	**18**	**1**	1	3	4	3.19E+00	4.85E-02	5.47E-03	1.48E-01	4.44E+00	1.60E+01	No
6	**19**	**1**	1	4	4	9.66E+00	4.85E-02	4.10E-03	1.11E-01	3.98E+00	1.60E+01	No
6	**24**	**1**	1	4	4	9.66E+00	4.85E-02	4.10E-03	1.11E-01	2.49E+00	1.60E+01	No
6	**45**	**1**	1	2	4	2.38E+00	4.85E-02	8.21E-03	1.57E-01	4.14E-01	1.60E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
7	CW	5	2	-1	8		6.18E-04	2.46E-02	2.34E-01			No
7	3	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	5.05E-01	3.03E+00	Yes
7	5	1	1	4	4	1.23E-01	6.18E-04	4.10E-03	1.11E-01	4.48E-01	3.03E+00	Yes
7	11	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	6.64E-01	3.16E+00	Yes
7	19	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	2.67E-01	1.07E+00	No
7	27	1	1	2	4	1.23E-01	6.18E-04	2.74E-03	7.40E-02	1.55E-01	1.07E+00	No
7	28	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	1.41E-01	1.07E+00	No
7	39	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	1.79E-01	1.07E+00	No
7	41	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	9.09E-02	1.07E+00	No
7	51	1	1	1	4	1.23E-01	6.18E-04	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
7	52	2	2	5	4	1.23E-01	6.18E-04	8.21E-03	1.65E-01	8.72E-02	1.07E+00	No
8	CW	6	2	-2	8		5.13E-03	2.87E-02	3.01E-01			No
8	4	1	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	5.50E-01	3.93E+00	Yes
8	5	1	1	3	4	1.02E+00	5.13E-03	4.10E-03	8.27E-02	5.82E-01	3.93E+00	Yes
8	10	2	1	2	4	1.02E+00	5.13E-03	5.47E-03	9.05E-02	4.60E-01	3.93E+00	Yes
8	15	1	1	3	4	1.02E+00	5.13E-03	2.74E-03	7.40E-02	3.26E-01	1.39E+00	No
8	17	1	1	1	4	1.02E+00	5.13E-03	4.10E-03	6.40E-02	3.57E-01	1.39E+00	No
8	25	1	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	4.53E-01	3.28E+00	No
8	35	1	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	4.39E-01	1.39E+00	No
8	46	1	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	6.96E-02	1.39E+00	No
8	52	1	1	1	4	1.02E+00	5.13E-03	1.37E-03	3.70E-02	1.13E-01	1.39E+00	No
8	53	2	1	1	4	1.02E+00	5.13E-03	5.47E-03	7.38E-02	2.00E-01	1.39E+00	No
9	CW	2	2	-1	8		4.07E-05	5.47E-03	9.06E-02			Yes
9	18	1	1	1	4	8.10E-03	4.07E-05	1.37E-03	3.70E-02	2.38E-01	8.58E-01	No
9	35	1	1	3	4	8.10E-03	4.07E-05	2.74E-03	7.40E-02	2.70E-01	8.58E-01	No
9	47	1	1	1	4	8.10E-03	4.07E-05	1.37E-03	3.70E-02	1.15E-01	8.58E-01	No
10	CW	4	2	-1	8		9.21E-04	1.64E-02	3.22E-01			No
10	21	1	1	4	4	1.83E-01	9.21E-04	4.10E-03	1.11E-01	8.99E-01	4.50E+00	No
10	45	3	2	11	4	1.83E-01	9.21E-04	1.09E-02	2.96E-01	1.17E-01	4.50E+00	No
10	53	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	6.47E-01	4.50E+00	No
11	CW	13	2	-3	8		1.93E-03	6.70E-02	5.51E-01			No
11	9	1	1	3	4	3.83E-01	1.93E-03	2.74E-03	7.40E-02	3.55E+00	2.60E+01	Yes
11	10	1	1	1	4	3.83E-01	1.93E-03	1.37E-03	3.70E-02	2.93E+00	2.51E+01	Yes
11	13	1	1	4	4	3.83E-01	1.93E-03	4.10E-03	1.11E-01	2.03E+00	8.90E+00	No
11	14	2	2	4	4	3.83E-01	1.93E-03	8.21E-03	1.38E-01	2.39E+00	8.90E+00	No
11	21	2	1	3	4	3.83E-01	1.93E-03	5.47E-03	1.05E-01	1.78E+00	8.90E+00	No
11	31	4	2	6	4	3.83E-01	1.93E-03	2.05E-02	2.53E-01	2.20E+00	8.90E+00	No
11	38	1	1	3	4	3.83E-01	1.93E-03	2.74E-03	7.40E-02	1.54E+00	8.90E+00	No
11	41	3	2	12	4	3.83E-01	1.93E-03	1.09E-02	2.96E-01	7.54E-01	8.90E+00	No
11	46	1	1	1	4	3.83E-01	1.93E-03	2.74E-03	5.23E-02	4.44E-01	8.90E+00	No
11	53	2	2	9	4	3.83E-01	1.93E-03	8.21E-03	2.22E-01	1.28E+00	8.90E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
12	CW	6	2	-1	8		3.33E-04	3.14E-02	4.12E-01			No
12	17	3	2	6	4	6.62E-02	3.33E-04	1.09E-02	2.15E-01	8.24E-02	3.22E-01	No
12	23	3	2	11	4	6.62E-02	3.33E-04	1.09E-02	2.96E-01	5.43E-02	3.22E-01	No
12	35	1	1	3	4	6.62E-02	3.33E-04	2.74E-03	7.40E-02	1.01E-01	3.22E-01	No
12	44	2	2	5	4	6.62E-02	3.33E-04	6.83E-03	1.52E-01	4.45E-02	3.22E-01	No
13	CW	3	2	-1	8		1.76E-02	1.09E-02	1.52E-01			No
13	16	1	1	1	4	3.51E+00	1.76E-02	2.74E-03	5.23E-02	1.01E+00	3.97E+00	No
13	20	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	1.16E+00	3.97E+00	No
13	27	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.73E-01	3.97E+00	No
13	28	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.23E-01	3.97E+00	No
13	33	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	6.53E-01	3.97E+00	No
13	37	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.44E-01	3.97E+00	No
13	48	1	1	1	4	3.51E+00	1.76E-02	1.37E-03	3.70E-02	5.26E-01	3.97E+00	No
14	CW	133	3	-25	8		9.02E-04	1.34E+00	7.95E+00			No
14	9	4	2	22	4	1.80E-01	9.02E-04	2.05E-02	5.55E-01	1.58E+00	1.16E+01	Yes
14	15	43	2	65	4	1.80E-01	9.02E-04	2.30E-01	2.93E+00	9.27E-01	3.97E+00	No
14	16	32	2	73	4	5.93E-02	9.02E-04	3.34E-01	4.06E+00	1.01E+00	3.97E+00	No
14	19	28	2	80	4	1.80E-01	9.02E-04	1.48E-01	2.73E+00	9.88E-01	3.97E+00	No
14	27	10	2	52	4	1.80E-01	9.02E-04	4.92E-02	1.33E+00	5.73E-01	3.97E+00	No
14	31	5	2	12	4	1.80E-01	9.02E-04	2.19E-02	4.05E-01	9.82E-01	3.97E+00	No
14	32	15	2	39	4	1.80E-01	9.02E-04	7.80E-02	1.34E+00	8.87E-01	3.97E+00	No
14	33	17	2	47	4	1.80E-01	9.02E-04	8.76E-02	1.62E+00	6.53E-01	3.97E+00	No
14	46	31	2	80	4	5.93E-02	9.02E-04	3.20E-01	4.08E+00	1.98E-01	3.97E+00	No
14	53	9	2	41	4	1.80E-01	9.02E-04	4.79E-02	1.12E+00	5.70E-01	3.97E+00	No
15	CW	5	2	-1	8		1.20E-03	2.19E-02	3.05E-01			No
15	16	2	1	5	4	2.39E-01	1.20E-03	5.47E-03	1.48E-01	1.01E+00	3.97E+00	No
15	27	2	1	5	4	2.39E-01	1.20E-03	5.47E-03	1.48E-01	5.73E-01	3.97E+00	No
15	42	3	2	6	4	2.39E-01	1.20E-03	1.09E-02	2.09E-01	4.23E-02	3.97E+00	No
16	CW	7	2	-2	8		3.53E-02	6.70E-02	3.60E-01			No
16	1	1	1	1	4	7.02E+00	3.53E-02	1.37E-03	3.70E-02	2.89E+01	1.45E+02	Yes
16	5	1	1	3	4	7.02E+00	3.53E-02	2.74E-03	7.40E-02	2.14E+01	1.45E+02	Yes
16	8	1	1	1	4	7.02E+00	3.53E-02	1.37E-03	3.70E-02	1.63E+01	1.47E+02	Yes
16	13	2	1	2	4	1.73E+00	3.53E-02	1.09E-02	1.38E-01	1.17E+01	5.13E+01	No
16	17	1	1	2	4	2.32E+00	3.53E-02	8.21E-03	1.17E-01	1.31E+01	5.13E+01	No
16	23	2	1	2	4	1.73E+00	3.53E-02	1.64E-02	1.65E-01	8.66E+00	5.13E+01	No
16	28	2	1	3	4	7.02E+00	3.53E-02	5.47E-03	1.05E-01	6.76E+00	5.13E+01	No
16	30	1	1	3	4	7.02E+00	3.53E-02	2.74E-03	7.40E-02	1.37E+01	5.13E+01	No
16	36	1	1	2	4	2.32E+00	3.53E-02	6.84E-03	9.77E-02	1.03E+01	5.13E+01	No
16	47	2	1	2	4	1.73E+00	3.53E-02	1.09E-02	1.57E-01	6.89E+00	5.13E+01	No
17	CW	1	1	-1	8		1.35E-02	4.10E-03	6.41E-02			No
17	42	1	1	1	4	2.69E+00	1.35E-02	1.37E-03	3.70E-02	5.26E-02	4.93E+00	No
17	43	1	1	1	4	2.69E+00	1.35E-02	1.37E-03	3.70E-02	2.35E-01	4.93E+00	No
17	46	1	1	1	4	2.69E+00	1.35E-02	1.37E-03	3.70E-02	2.46E-01	4.93E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
18	CW	7	2	-2	8		1.19E-02	3.42E-02	2.91E-01			No
18	15	2	2	5	4	2.37E+00	1.19E-02	6.84E-03	1.52E-01	3.21E+00	1.37E+01	No
18	27	2	1	3	4	2.37E+00	1.19E-02	5.47E-03	1.05E-01	1.98E+00	1.37E+01	No
18	35	1	1	3	4	2.37E+00	1.19E-02	2.74E-03	7.40E-02	4.32E+00	1.37E+01	No
18	36	2	2	4	4	2.37E+00	1.19E-02	8.21E-03	1.38E-01	2.76E+00	1.37E+01	No
18	42	2	2	3	4	2.37E+00	1.19E-02	8.21E-03	1.28E-01	1.46E-01	1.37E+01	No
18	44	1	1	3	4	2.37E+00	1.19E-02	2.74E-03	7.40E-02	1.90E+00	1.37E+01	No
19	CW	6	2	-2	8		3.24E-03	2.87E-02	5.05E-01			No
19	25	1	1	1	4	6.45E-01	3.24E-03	1.37E-03	3.70E-02	2.75E+00	2.00E+01	No
19	43	1	1	1	4	6.45E-01	3.24E-03	1.37E-03	3.70E-02	4.04E-01	8.47E+00	No
19	45	5	2	17	4	6.45E-01	3.24E-03	2.60E-02	4.80E-01	2.20E-01	8.47E+00	No
20	CW	28	2	-5	8		1.59E-04	1.42E-01	1.57E+00			No
20	22	15	2	34	4	3.16E-02	1.59E-04	7.66E-02	1.21E+00	3.76E-02	2.14E-01	No
20	34	6	2	16	4	3.16E-02	1.59E-04	2.74E-02	5.25E-01	3.12E-02	2.14E-01	No
20	43	5	2	16	4	3.16E-02	1.59E-04	2.46E-02	4.96E-01	1.02E-02	2.14E-01	No
20	48	3	2	15	4	3.16E-02	1.59E-04	1.37E-02	3.70E-01	2.84E-02	2.14E-01	No
21	CW	1	1	-1	8		6.31E-01	1.64E-02	2.19E-01			No
21	15	1	1	0	4	1.74E+01	6.31E-01	1.37E-03	3.70E-02	7.52E+02	3.22E+03	No
21	16	1	1	1	4	1.20E+01	6.31E-01	4.10E-03	6.40E-02	8.19E+02	3.22E+03	No
21	28	1	1	0	4	1.74E+01	6.31E-01	1.37E-03	3.70E-02	4.24E+02	3.22E+03	No
21	34	1	1	1	4	9.88E+00	6.31E-01	8.21E-03	9.03E-02	4.68E+02	3.22E+03	No
21	42	1	1	0	4	1.74E+01	6.31E-01	1.37E-03	3.70E-02	3.43E+01	3.22E+03	No
22	CW	3	2	-1	8		3.65E-02	1.50E-02	2.76E-01			No
22	25	1	1	1	4	7.26E+00	3.65E-02	1.37E-03	3.70E-02	1.01E+01	7.30E+01	No
22	42	1	1	1	4	7.26E+00	3.65E-02	1.37E-03	3.70E-02	3.30E-01	3.10E+01	No
22	45	2	1	1	4	7.26E+00	3.65E-02	5.47E-03	7.38E-02	8.04E-01	3.10E+01	No
22	46	1	1	1	4	7.26E+00	3.65E-02	2.74E-03	5.23E-02	1.55E+00	3.10E+01	No
22	51	1	1	1	4	7.26E+00	3.65E-02	2.74E-03	5.23E-02	2.09E+00	3.10E+01	No
22	52	1	1	1	4	7.26E+00	3.65E-02	1.37E-03	3.70E-02	2.52E+00	3.10E+01	No
23	CW	38	3	-13	8		4.86E-03	3.82E-01	1.65E+00			No
23	12	3	2	5	4	9.68E-01	4.86E-03	1.09E-02	1.81E-01	1.94E+00	8.58E+00	No
23	15	6	2	6	4	3.19E-01	4.86E-03	5.31E-02	4.32E-01	2.00E+00	8.58E+00	No
23	18	5	2	6	4	9.68E-01	4.86E-03	2.46E-02	2.75E-01	2.38E+00	8.58E+00	No
23	20	3	2	9	4	9.68E-01	4.86E-03	1.37E-02	2.67E-01	2.50E+00	8.58E+00	No
23	27	8	2	6	4	9.68E-01	4.86E-03	3.97E-02	3.43E-01	1.24E+00	8.58E+00	No
23	36	4	2	6	4	9.68E-01	4.86E-03	1.78E-02	2.30E-01	1.73E+00	8.58E+00	No
23	37	5	2	6	4	9.68E-01	4.86E-03	2.32E-02	2.78E-01	1.18E+00	8.58E+00	No
23	42	11	2	8	4	2.38E-01	4.86E-03	1.05E-01	6.92E-01	9.14E-02	8.58E+00	No
23	45	6	2	8	4	3.19E-01	4.86E-03	5.74E-02	4.93E-01	2.23E-01	8.58E+00	No
23	46	7	2	7	4	9.68E-01	4.86E-03	3.69E-02	3.62E-01	4.28E-01	8.58E+00	No
24	CW	2	2	-1	8		1.17E-02	6.84E-03	1.82E-01			Yes
24	35	1	1	1	4	2.33E+00	1.17E-02	4.10E-03	6.40E-02	5.40E-01	1.72E+00	No
24	36	1	1	1	4	2.33E+00	1.17E-02	2.74E-03	5.23E-02	3.45E-01	1.72E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
25	CW	3	2	-1	8		1.46E-03	1.37E-02	2.06E-01			No
25	8	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	1.60E+00	1.45E+01	Yes
25	14	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	1.35E+00	5.04E+00	No
25	22	2	2	7	4	2.91E-01	1.46E-03	6.84E-03	1.85E-01	8.83E-01	5.04E+00	No
25	29	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	6.00E-01	5.04E+00	No
25	43	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	2.41E-01	5.04E+00	No
25	50	1	1	1	4	2.91E-01	1.46E-03	1.37E-03	3.70E-02	9.04E-01	5.04E+00	No
26	CW	3	2	-1	8		8.14E-02	2.74E-02	2.94E-01			No
26	13	1	1	1	4	3.99E+00	8.14E-02	5.47E-03	7.38E-02	2.53E+01	1.11E+02	No
26	14	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.98E+01	1.11E+02	No
26	17	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.84E+01	1.11E+02	No
26	19	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	2.76E+01	1.11E+02	No
26	20	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	3.23E+01	1.11E+02	No
26	27	1	1	1	4	3.99E+00	8.14E-02	5.47E-03	7.38E-02	1.60E+01	1.11E+02	No
26	34	1	1	1	4	3.99E+00	8.14E-02	5.47E-03	7.38E-02	1.61E+01	1.11E+02	No
26	36	1	1	1	4	1.62E+01	8.14E-02	2.74E-03	5.23E-02	2.23E+01	1.11E+02	No
26	43	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	5.29E+00	1.11E+02	No
26	49	1	1	1	4	1.62E+01	8.14E-02	1.37E-03	3.70E-02	1.68E+01	1.11E+02	No
27	CW	9	2	-2	8		1.22E-03	4.38E-02	3.09E-01			No
27	14	1	1	2	4	2.42E-01	1.22E-03	4.10E-03	8.27E-02	5.76E-02	2.14E-01	No
27	17	2	2	3	4	2.42E-01	1.22E-03	8.21E-03	1.28E-01	5.49E-02	2.14E-01	No
27	18	1	1	3	4	2.42E-01	1.22E-03	2.74E-03	7.40E-02	5.96E-02	2.14E-01	No
27	26	1	1	1	4	2.42E-01	1.22E-03	1.37E-03	3.70E-02	7.70E-02	5.13E-01	No
27	31	1	1	3	4	2.42E-01	1.22E-03	2.74E-03	7.40E-02	5.31E-02	2.14E-01	No
27	33	2	1	3	4	2.42E-01	1.22E-03	5.47E-03	1.05E-01	3.53E-02	2.14E-01	No
27	34	1	1	3	4	2.42E-01	1.22E-03	2.74E-03	7.40E-02	3.12E-02	2.14E-01	No
27	35	2	1	3	4	2.42E-01	1.22E-03	5.47E-03	1.05E-01	6.76E-02	2.14E-01	No
27	46	2	1	3	4	2.42E-01	1.22E-03	5.47E-03	1.05E-01	1.07E-02	2.14E-01	No
27	50	2	1	5	4	2.42E-01	1.22E-03	5.47E-03	1.48E-01	3.85E-02	2.14E-01	No
28	CW	3	2	-1	8		1.06E-02	1.23E-02	1.52E-01			No
28	22	1	1	3	4	2.11E+00	1.06E-02	2.74E-03	7.40E-02	1.71E+00	9.76E+00	No
28	24	1	1	1	4	2.11E+00	1.06E-02	1.37E-03	3.70E-02	1.52E+00	9.76E+00	No
28	27	2	1	3	4	2.11E+00	1.06E-02	5.47E-03	1.05E-01	1.41E+00	9.76E+00	No
28	36	1	1	3	4	2.11E+00	1.06E-02	2.74E-03	7.40E-02	1.96E+00	9.76E+00	No
29	CW	4	2	-2	8		1.02E-01	5.34E-02	4.35E-01			No
29	13	1	1	1	4	2.82E+00	1.02E-01	1.09E-02	1.04E-01	3.71E+01	1.63E+02	No
29	22	1	1	1	4	5.02E+00	1.02E-01	4.10E-03	6.40E-02	2.85E+01	1.63E+02	No
29	28	1	1	1	4	2.82E+00	1.02E-01	1.09E-02	1.04E-01	2.15E+01	1.63E+02	No
29	33	1	1	1	4	6.73E+00	1.02E-01	2.74E-03	5.23E-02	2.68E+01	1.63E+02	No
29	37	1	1	1	4	3.31E+00	1.02E-01	6.84E-03	8.25E-02	2.23E+01	1.63E+02	No
29	38	1	1	1	4	3.31E+00	1.02E-01	6.84E-03	8.25E-02	2.81E+01	1.63E+02	No
29	46	1	1	1	4	5.02E+00	1.02E-01	4.10E-03	6.40E-02	8.13E+00	1.63E+02	No
29	47	1	1	1	4	2.04E+01	1.02E-01	1.37E-03	3.70E-02	2.19E+01	1.63E+02	No
29	49	1	1	1	4	6.73E+00	1.02E-01	2.74E-03	5.23E-02	2.47E+01	1.63E+02	No
29	52	1	1	1	4	6.73E+00	1.02E-01	2.74E-03	5.23E-02	1.32E+01	1.63E+02	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
30	CW	1	1	-1	8		3.42E-02	2.74E-03	1.22E-01			No
30	42	1	1	1	4	6.81E+00	3.42E-02	2.74E-03	5.23E-02	3.45E-01	3.24E+01	No
31	CW	8	2	-2	8		1.93E-02	4.10E-02	3.89E-01			No
31	25	2	1	3	4	3.85E+00	1.93E-02	5.47E-03	1.05E-01	4.88E+01	3.54E+02	No
31	27	1	1	4	4	3.85E+00	1.93E-02	4.10E-03	1.11E-01	2.17E+01	1.50E+02	No
31	35	1	1	1	4	3.85E+00	1.93E-02	2.74E-03	5.23E-02	4.73E+01	1.50E+02	No
31	36	2	2	9	4	3.85E+00	1.93E-02	8.21E-03	2.22E-01	3.02E+01	1.50E+02	No
31	45	3	2	5	4	3.85E+00	1.93E-02	1.23E-02	1.92E-01	3.89E+00	1.50E+02	No
31	46	2	2	5	4	3.85E+00	1.93E-02	8.20E-03	1.65E-01	7.49E+00	1.50E+02	No
32	CW	3	2	-1	8		7.10E-03	1.23E-02	1.48E-01			No
32	39	1	1	1	4	1.43E+00	7.20E-03	1.37E-03	3.70E-02	2.33E-01	1.39E+00	No
32	43	1	1	1	4	1.43E+00	7.07E-03	1.37E-03	3.70E-02	6.66E-02	1.39E+00	No
32	45	2	1	2	4	1.43E+00	7.07E-03	6.84E-03	1.11E-01	3.62E-02	1.39E+00	No
32	46	1	1	3	4	1.43E+00	7.07E-03	2.74E-03	7.40E-02	6.96E-02	1.39E+00	No
33	CW	1	1	-1	8		9.56E-03	1.37E-03	3.70E-02			No
33	42	1	1	1	4	1.90E+00	9.56E-03	1.37E-03	3.70E-02	8.00E-03	7.51E-01	No
34	CW	4	2	-1	8		1.37E-02	2.05E-02	2.61E-01			No
34	22	1	1	4	4	2.72E+00	1.37E-02	4.10E-03	1.11E-01	2.23E+01	1.27E+02	No
34	24	2	1	5	4	2.72E+00	1.37E-02	5.47E-03	1.48E-01	1.98E+01	1.27E+02	No
34	27	1	1	3	4	2.72E+00	1.37E-02	2.74E-03	7.40E-02	1.84E+01	1.27E+02	No
34	29	1	1	1	4	2.72E+00	1.37E-02	2.74E-03	5.23E-02	1.52E+01	1.27E+02	No
34	38	1	1	4	4	2.72E+00	1.37E-02	4.10E-03	1.11E-01	2.20E+01	1.27E+02	No
34	51	1	1	1	4	2.72E+00	1.37E-02	1.37E-03	3.70E-02	8.58E+00	1.27E+02	No
35	CW	2	2	-1	8		2.11E-03	8.21E-03	1.52E-01			No
35	19	1	1	1	4	4.20E-01	2.11E-03	1.37E-03	3.70E-02	3.21E-01	1.29E+00	No
35	35	1	1	3	4	4.20E-01	2.11E-03	2.74E-03	7.40E-02	4.05E-01	1.29E+00	No
35	40	1	1	1	4	4.20E-01	2.11E-03	2.74E-03	5.23E-02	1.20E-01	1.29E+00	No
35	41	1	1	1	4	4.20E-01	2.11E-03	1.37E-03	3.70E-02	1.09E-01	1.29E+00	No
36	CW	2	1	-1	8		2.32E-01	1.23E-02	1.52E-01			No
36	5	1	1	0	4	1.52E+01	2.32E-01	1.37E-03	3.70E-02	1.64E+02	1.11E+03	Yes
36	22	1	1	0	4	1.52E+01	2.32E-01	1.37E-03	3.70E-02	6.88E+01	3.92E+02	No
36	32	1	1	0	4	1.52E+01	2.32E-01	1.37E-03	3.70E-02	8.78E+01	3.92E+02	No
36	44	1	1	2	4	5.56E+00	2.32E-01	5.47E-03	1.17E-01	5.43E+01	3.92E+02	No
36	48	1	1	1	4	7.49E+00	2.32E-01	2.74E-03	7.40E-02	5.20E+01	3.92E+02	No
37	CW	1	1	-1	8		9.85E-01	1.92E-02	2.40E-01			No
37	15	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	7.67E+00	3.28E+01	No
37	16	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	8.36E+00	3.28E+01	No
37	19	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	8.17E+00	3.28E+01	No
37	22	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	5.75E+00	3.28E+01	No
37	24	1	1	1	4	1.87E+01	9.85E-01	2.74E-03	5.23E-02	5.10E+00	3.28E+01	No
37	25	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	1.07E+01	7.73E+01	No
37	31	1	1	1	4	1.54E+01	9.85E-01	4.10E-03	6.40E-02	8.12E+00	3.28E+01	No
37	42	1	1	1	4	1.87E+01	9.85E-01	2.74E-03	5.23E-02	3.50E-01	3.28E+01	No
37	43	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	1.57E+00	3.28E+01	No
37	49	1	1	0	4	2.36E+01	9.85E-01	1.37E-03	3.70E-02	4.97E+00	3.28E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
38	CW	12	2	-2	8		1.14E-02	1.20E-01	8.75E-01			No
38	13	2	2	8	4	2.28E+00	1.14E-02	8.21E-03	2.22E-01	2.47E+00	1.08E+01	No
38	27	5	2	9	4	2.28E+00	1.14E-02	2.46E-02	3.84E-01	1.56E+00	1.08E+01	No
38	31	4	2	8	4	2.28E+00	1.14E-02	2.05E-02	3.32E-01	2.68E+00	1.08E+01	No
38	42	5	2	9	4	2.28E+00	1.14E-02	2.60E-02	3.86E-01	1.15E-01	1.08E+01	No
38	45	2	2	8	4	2.28E+00	1.14E-02	8.21E-03	2.22E-01	2.81E-01	1.08E+01	No
38	46	2	2	8	4	2.28E+00	1.14E-02	8.21E-03	2.22E-01	5.41E-01	1.08E+01	No
38	47	2	2	8	4	2.28E+00	1.14E-02	8.21E-03	2.22E-01	1.46E+00	1.08E+01	No
38	49	4	2	9	4	2.28E+00	1.14E-02	1.64E-02	3.14E-01	1.64E+00	1.08E+01	No
39	CW	1	1	-1	8		2.79E-01	4.10E-03	1.27E-01			No
39	42	1	1	1	4	9.02E+00	2.79E-01	2.74E-03	5.23E-02	1.71E-01	1.61E+01	No
39	48	1	1	0	4	1.37E+01	2.79E-01	1.37E-03	3.70E-02	2.13E+00	1.61E+01	No
40	CW	2	2	-1	14		7.49E-02	9.57E-03	1.33E-01			No
40	20	1	1	3	4	1.49E+01	7.49E-02	2.74E-03	7.40E-02	4.06E+01	1.39E+02	No
40	22	1	1	2	4	4.92E+00	7.49E-02	4.10E-03	8.26E-02	2.44E+01	1.39E+02	No
40	42	1	1	3	4	1.49E+01	7.49E-02	2.74E-03	7.40E-02	1.49E+00	1.39E+02	No
41	CW	28	3	1	15		2.65E-02	4.49E-01	2.34E+00			No
41	34	2	2	7	4	5.28E+00	2.65E-02	6.84E-03	1.85E-01	7.80E+00	5.36E+01	No
41	42	6	2	15	4	4.16E-01	2.65E-02	1.24E-01	1.20E+00	5.71E-01	5.36E+01	No
41	43	3	1	11	4	6.37E-01	2.65E-02	5.34E-02	7.50E-01	2.56E+00	5.36E+01	No
41	45	7	2	11	4	4.16E-01	2.65E-02	1.60E-01	1.23E+00	1.39E+00	5.36E+01	No
41	46	3	1	9	4	8.58E-01	2.65E-02	3.28E-02	5.43E-01	2.68E+00	5.36E+01	No
41	51	3	1	25	4	6.37E-01	2.65E-02	5.06E-02	1.06E+00	3.61E+00	5.36E+01	No
41	52	3	1	11	4	1.30E+00	2.65E-02	2.19E-02	4.56E-01	4.36E+00	5.36E+01	No
42	CW	2	2	-1	12		1.58E-01	5.47E-03	1.28E-01			No
42	6	1	1	1	4	3.14E+01	1.58E-01	1.37E-03	3.70E-02	7.66E+02	7.57E+03	Yes
42	53	1	1	1	4	5.10E+00	1.58E-01	4.10E-03	6.40E-02	3.85E+02	2.68E+03	No
43	CW	1	1	-1	15		1.75E-03	2.74E-03	5.23E-02			No
43	31	1	1	1	4	3.47E-01	1.75E-03	1.37E-03	3.70E-02	2.39E-01	9.65E-01	No
43	49	1	1	1	4	3.47E-01	1.75E-03	1.37E-03	3.70E-02	1.46E-01	9.65E-01	No
44	CW	2	2	-1	15		2.38E-02	8.21E-03	2.05E-01			Yes
44	15	2	1	1	4	5.09E+00	2.56E-02	5.47E-03	7.38E-02	1.25E+01	5.36E+01	No
44	53	1	1	1	4	5.09E+00	2.21E-02	2.74E-03	5.23E-02	7.71E+00	5.36E+01	No
45	CW	7	2	-2	12		2.82E-02	3.56E-02	2.86E-01			No
45	5	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.34E+00	9.08E+00	Yes
45	6	2	1	4	4	1.85E+00	2.82E-02	1.09E-02	1.81E-01	9.19E-01	9.08E+00	Yes
45	10	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.06E+00	9.08E+00	Yes
45	13	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	7.34E-01	3.22E+00	No
45	14	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	8.65E-01	3.22E+00	No
45	15	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	7.52E-01	3.22E+00	No
45	22	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	5.64E-01	3.22E+00	No
45	25	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	1.04E+00	7.58E+00	No
45	30	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	8.59E-01	3.22E+00	No
45	44	1	1	3	4	5.60E+00	2.82E-02	2.74E-03	7.40E-02	4.45E-01	3.22E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
46	CW	8	2	-2	10		2.68E-02	3.83E-02	3.16E-01			No
46	9	1	1	1	4	5.33E+00	2.68E-02	1.37E-03	3.70E-02	4.70E-01	3.44E+00	Yes
46	15	1	1	3	4	5.33E+00	2.68E-02	2.74E-03	7.40E-02	2.76E-01	1.18E+00	No
46	21	1	1	3	4	5.33E+00	2.68E-02	2.74E-03	7.40E-02	2.36E-01	1.18E+00	No
46	23	1	1	3	4	5.33E+00	2.68E-02	2.74E-03	7.40E-02	1.99E-01	1.18E+00	No
46	34	1	1	5	4	5.33E+00	2.68E-02	4.10E-03	1.11E-01	1.72E-01	1.18E+00	No
46	42	2	1	3	4	5.33E+00	2.68E-02	5.47E-03	1.05E-01	1.26E-02	1.18E+00	No
46	45	1	1	1	4	5.33E+00	2.68E-02	1.37E-03	3.70E-02	3.06E-02	1.18E+00	No
46	52	2	1	5	4	1.76E+00	2.68E-02	1.09E-02	2.09E-01	9.59E-02	1.18E+00	No
46	53	2	1	3	4	5.33E+00	2.68E-02	6.84E-03	1.11E-01	1.70E-01	1.18E+00	No
47	CW	4	2	-1	10		6.23E-02	1.64E-02	1.72E-01			No
47	1	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	1.82E+00	9.08E+00	Yes
47	5	1	1	1	4	1.24E+01	6.23E-02	2.74E-03	5.23E-02	1.34E+00	9.08E+00	Yes
47	23	1	1	3	4	1.24E+01	6.23E-02	2.74E-03	7.40E-02	5.43E-01	3.22E+00	No
47	27	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.64E-01	3.22E+00	No
47	34	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.68E-01	3.22E+00	No
47	42	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	3.43E-02	3.22E+00	No
47	47	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.33E-01	3.22E+00	No
47	48	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.27E-01	3.22E+00	No
47	49	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	4.87E-01	3.22E+00	No
47	50	1	1	1	4	1.24E+01	6.23E-02	1.37E-03	3.70E-02	5.77E-01	3.22E+00	No
48	CW	2	2	-1	10		5.69E-02	8.21E-03	1.71E-01			No
48	7	1	1	1	4	1.13E+01	5.69E-02	2.74E-03	5.23E-02	1.47E+00	1.23E+01	Yes
48	8	1	1	1	4	1.13E+01	5.69E-02	2.74E-03	5.23E-02	1.36E+00	1.23E+01	Yes
48	40	1	1	1	4	1.13E+01	5.69E-02	1.37E-03	3.70E-02	4.01E-01	4.29E+00	No
48	48	1	1	1	4	1.13E+01	5.69E-02	1.37E-03	3.70E-02	5.69E-01	4.29E+00	No
49	CW	1	1	-1	14		1.14E+00	2.74E-03	1.06E-01			No
49	51	1	1	1	4	1.78E+01	1.14E+00	2.74E-03	5.23E-02	7.22E+02	1.07E+04	No
50	CW	2	2	-1	10		3.99E-01	1.92E-02	2.48E-01			No
50	12	1	1	1	4	1.10E+01	3.99E-01	2.74E-03	5.23E-02	4.36E+00	1.93E+01	No
50	19	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	4.81E+00	1.93E+01	No
50	27	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	2.79E+00	1.93E+01	No
50	31	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	4.77E+00	1.93E+01	No
50	35	1	1	1	4	1.10E+01	3.99E-01	2.74E-03	5.23E-02	6.08E+00	1.93E+01	No
50	36	1	1	1	4	1.10E+01	3.99E-01	2.74E-03	5.23E-02	3.88E+00	1.93E+01	No
50	39	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	3.22E+00	1.93E+01	No
50	42	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	2.06E-01	1.93E+01	No
50	43	1	1	0	4	1.29E+01	3.99E-01	1.37E-03	3.70E-02	9.21E-01	1.93E+01	No
50	47	1	1	1	4	1.10E+01	3.99E-01	2.74E-03	5.23E-02	2.60E+00	1.93E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
51	CW	5	2	-1	10		7.44E-03	2.46E-02	2.50E-01			No
51	19	3	2	4	4	1.48E+00	7.44E-03	1.09E-02	1.73E-01	2.67E-01	1.07E+00	No
51	21	1	1	1	4	1.48E+00	7.44E-03	1.37E-03	3.70E-02	2.14E-01	1.07E+00	No
51	23	1	1	1	4	1.48E+00	7.44E-03	2.74E-03	5.23E-02	1.81E-01	1.07E+00	No
51	26	1	1	3	4	1.48E+00	7.44E-03	2.74E-03	7.40E-02	3.85E-01	2.57E+00	No
51	29	1	1	3	4	1.48E+00	7.44E-03	2.74E-03	7.40E-02	1.28E-01	1.07E+00	No
51	37	1	1	1	4	1.48E+00	7.44E-03	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
51	45	1	1	1	4	1.48E+00	7.44E-03	1.37E-03	3.70E-02	2.78E-02	1.07E+00	No
51	51	1	1	1	4	1.48E+00	7.44E-03	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
52	CW	3	2	-1	10		4.89E-03	1.50E-02	1.60E-01			No
52	7	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	7.37E-01	6.17E+00	Yes
52	16	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.46E-01	2.14E+00	No
52	17	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.49E-01	2.14E+00	No
52	19	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	5.34E-01	2.14E+00	No
52	20	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	6.24E-01	2.14E+00	No
52	23	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	3.62E-01	2.14E+00	No
52	35	1	1	1	4	9.73E-01	4.89E-03	2.74E-03	5.23E-02	6.76E-01	2.14E+00	No
52	41	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	1.82E-01	2.14E+00	No
52	43	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	1.02E-01	2.14E+00	No
52	50	1	1	1	4	9.73E-01	4.89E-03	1.37E-03	3.70E-02	3.85E-01	2.14E+00	No
53	CW	6	2	-1	10		3.11E-02	2.60E-02	2.30E-01			No
53	3	1	1	1	4	6.23E+00	3.13E-02	2.74E-03	5.23E-02	5.55E+00	3.33E+01	Yes
53	6	1	1	2	4	6.23E+00	3.13E-02	4.10E-03	8.27E-02	3.37E+00	3.33E+01	Yes
53	8	1	1	2	4	6.23E+00	3.08E-02	2.74E-03	7.40E-02	3.75E+00	3.39E+01	Yes
53	15	1	1	2	4	6.23E+00	3.08E-02	4.10E-03	8.26E-02	2.76E+00	1.18E+01	No
53	17	1	1	1	4	6.23E+00	3.15E-02	1.37E-03	3.70E-02	3.02E+00	1.18E+01	No
53	19	1	1	2	4	6.23E+00	3.15E-02	2.74E-03	7.40E-02	2.94E+00	1.18E+01	No
53	20	1	1	1	4	6.23E+00	3.15E-02	1.37E-03	3.70E-02	3.43E+00	1.18E+01	No
53	33	1	1	2	4	6.23E+00	3.09E-02	2.74E-03	7.40E-02	1.94E+00	1.18E+01	No
53	35	1	1	1	4	6.23E+00	3.09E-02	1.37E-03	3.70E-02	3.72E+00	1.18E+01	No
53	36	1	1	2	4	6.23E+00	3.09E-02	2.74E-03	7.40E-02	2.37E+00	1.18E+01	No
54	CW	3	2	-1	10		4.77E-02	2.33E-02	1.92E-01			No
54	10	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	4.24E+00	3.63E+01	Yes
54	17	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	3.30E+00	1.29E+01	No
54	26	1	1	3	4	9.49E+00	4.77E-02	2.74E-03	7.40E-02	4.62E+00	3.08E+01	No
54	32	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	2.88E+00	1.29E+01	No
54	35	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	4.05E+00	1.29E+01	No
54	41	1	1	2	4	3.13E+00	4.77E-02	5.47E-03	1.05E-01	1.09E+00	1.29E+01	No
54	42	1	1	2	4	9.49E+00	4.77E-02	4.10E-03	8.27E-02	1.37E-01	1.29E+01	No
54	45	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	3.34E-01	1.29E+01	No
54	48	1	1	3	4	9.49E+00	4.77E-02	2.74E-03	7.40E-02	1.71E+00	1.29E+01	No
54	50	1	1	1	4	9.49E+00	4.77E-02	1.37E-03	3.70E-02	2.31E+00	1.29E+01	No
55	CW	1	2	-1	15		1.11E-01	2.74E-03	7.40E-02			Yes
55	31	1	1	2	4	7.31E+00	1.11E-01	2.74E-03	7.40E-02	1.33E+00	5.36E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
56	CW	3	2	-1	10		3.55E-02	1.37E-02	1.91E-01			No
56	6	1	1	1	4	7.07E+00	3.55E-02	2.74E-03	5.23E-02	1.84E+00	1.82E+01	Yes
56	8	1	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	2.04E+00	1.85E+01	Yes
56	11	1	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	3.98E+00	1.90E+01	Yes
56	15	1	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	1.50E+00	6.43E+00	No
56	34	1	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	9.36E-01	6.43E+00	No
56	41	1	1	1	4	7.07E+00	3.55E-02	4.10E-03	6.40E-02	5.45E-01	6.43E+00	No
56	52	1	1	1	4	7.07E+00	3.55E-02	1.37E-03	3.70E-02	5.23E-01	6.43E+00	No
57	CW	1	1	-1	10		2.59E-02	1.37E-03	3.70E-02			No
57	38	1	1	1	4	5.16E+00	2.59E-02	1.37E-03	3.70E-02	1.42E+00	8.26E+00	No
58	CW	2	2	-1	10		8.15E-02	1.37E-02	1.56E-01			No
58	24	1	1	1	4	1.62E+01	8.15E-02	2.74E-03	5.23E-02	4.00E+00	2.57E+01	No
58	26	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	9.24E+00	6.16E+01	No
58	35	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	8.11E+00	2.57E+01	No
58	42	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	2.74E-01	2.57E+01	No
58	44	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.56E+00	2.57E+01	No
58	47	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.46E+00	2.57E+01	No
58	49	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.90E+00	2.57E+01	No
58	51	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	1.73E+00	2.57E+01	No
58	53	1	1	1	4	1.62E+01	8.15E-02	1.37E-03	3.70E-02	3.70E+00	2.57E+01	No
59	CW	4	2	-1	10		1.99E-02	1.64E-02	2.19E-01			No
59	16	1	1	1	4	3.95E+00	1.99E-02	2.74E-03	5.23E-02	2.73E-01	1.07E+00	No
59	26	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	3.85E-01	2.57E+00	No
59	32	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	2.40E-01	1.07E+00	No
59	34	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	1.56E-01	1.07E+00	No
59	37	1	1	1	4	3.95E+00	1.99E-02	2.74E-03	5.23E-02	1.47E-01	1.07E+00	No
59	42	1	1	1	4	3.95E+00	1.99E-02	2.74E-03	5.23E-02	1.14E-02	1.07E+00	No
59	43	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	5.12E-02	1.07E+00	No
59	47	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	1.44E-01	1.07E+00	No
59	52	1	1	1	4	3.95E+00	1.99E-02	1.37E-03	3.70E-02	8.72E-02	1.07E+00	No
60	CW	5	2	-2	10		2.76E-02	2.19E-02	2.60E-01			No
60	13	1	1	1	4	5.48E+00	2.76E-02	4.10E-03	6.40E-02	7.34E-02	3.22E-01	No
60	17	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	8.24E-02	3.22E-01	No
60	20	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	9.37E-02	3.22E-01	No
60	21	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	6.42E-02	3.22E-01	No
60	23	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	5.43E-02	3.22E-01	No
60	26	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	1.16E-01	7.70E-01	No
60	28	1	1	1	4	5.48E+00	2.76E-02	1.37E-03	3.70E-02	4.24E-02	3.22E-01	No
60	45	1	1	1	4	5.48E+00	2.76E-02	2.74E-03	5.23E-02	8.34E-03	3.22E-01	No
60	48	1	1	1	4	5.48E+00	2.76E-02	2.74E-03	5.23E-02	4.27E-02	3.22E-01	No
60	53	1	1	1	4	5.48E+00	2.76E-02	4.10E-03	6.40E-02	4.62E-02	3.22E-01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
61	CW	2	2	-1	10		3.94E-01	3.97E-02	3.60E-01			No
61	1	1	1	0	4	1.93E+01	3.95E-01	1.37E-03	3.70E-02	1.82E+01	9.08E+01	Yes
61	5	1	1	1	4	7.50E+00	3.95E-01	4.10E-03	6.40E-02	1.34E+01	9.08E+01	Yes
61	6	1	1	0	4	1.93E+01	3.95E-01	1.37E-03	3.70E-02	9.19E+00	9.08E+01	Yes
61	17	1	1	1	4	7.50E+00	3.95E-01	4.10E-03	6.40E-02	8.24E+00	3.22E+01	No
61	19	1	1	1	4	1.09E+01	3.95E-01	2.74E-03	5.23E-02	8.01E+00	3.22E+01	No
61	21	1	1	1	4	7.50E+00	3.95E-01	5.47E-03	7.38E-02	6.42E+00	3.22E+01	No
61	36	1	1	1	4	7.50E+00	3.91E-01	5.47E-03	7.38E-02	6.47E+00	3.22E+01	No
61	44	1	1	0	4	1.93E+01	3.92E-01	1.37E-03	3.70E-02	4.45E+00	3.22E+01	No
61	47	1	1	1	4	6.18E+00	3.92E-01	8.21E-03	9.03E-02	4.33E+00	3.22E+01	No
61	52	1	1	1	4	7.50E+00	3.95E-01	5.47E-03	7.38E-02	2.62E+00	3.22E+01	No
62	CW	2	2	-1	10		3.05E-01	4.24E-02	2.79E-01			No
62	2	1	1	1	4	8.40E+00	3.05E-01	2.74E-03	7.40E-02	3.12E+02	1.85E+03	Yes
62	4	1	1	1	4	5.79E+00	3.05E-01	5.47E-03	1.05E-01	2.45E+02	1.76E+03	Yes
62	5	1	1	1	4	5.79E+00	3.05E-01	9.58E-03	1.33E-01	2.60E+02	1.76E+03	Yes
62	27	1	1	1	4	8.40E+00	3.05E-01	2.74E-03	7.40E-02	8.98E+01	6.22E+02	No
62	37	1	1	0	4	1.49E+01	3.05E-01	1.37E-03	3.70E-02	8.52E+01	6.22E+02	No
62	41	1	1	1	4	5.79E+00	3.05E-01	5.47E-03	1.05E-01	5.27E+01	6.22E+02	No
62	42	1	1	1	4	5.79E+00	3.05E-01	9.58E-03	1.33E-01	6.63E+00	6.22E+02	No
62	45	1	1	1	4	8.40E+00	3.05E-01	2.74E-03	7.40E-02	1.61E+01	6.22E+02	No
62	46	1	1	0	4	1.49E+01	3.05E-01	1.37E-03	3.70E-02	3.10E+01	6.22E+02	No
62	51	1	1	0	4	1.49E+01	3.05E-01	1.37E-03	3.70E-02	4.19E+01	6.22E+02	No
63	CW	3	2	-1	10		1.69E-02	1.09E-02	1.47E-01			No
63	1	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	6.05E-01	3.03E+00	Yes
63	12	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	2.42E-01	1.07E+00	No
63	28	1	1	1	4	3.37E+00	1.69E-02	2.74E-03	5.23E-02	1.41E-01	1.07E+00	No
63	42	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	1.14E-02	1.07E+00	No
63	45	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	2.78E-02	1.07E+00	No
63	51	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	7.22E-02	1.07E+00	No
63	53	1	1	1	4	3.37E+00	1.69E-02	1.37E-03	3.70E-02	1.54E-01	1.07E+00	No
64	CW	2	2	-1	10		5.84E-01	3.83E-02	3.56E-01			No
64	1	1	1	0	4	1.89E+01	5.84E-01	1.37E-03	3.70E-02	3.17E+02	1.59E+03	Yes
64	13	1	1	1	4	9.14E+00	5.84E-01	6.84E-03	8.25E-02	1.28E+02	5.62E+02	No
64	25	1	1	1	4	9.14E+00	5.84E-01	5.47E-03	7.38E-02	1.83E+02	1.32E+03	No
64	26	1	1	1	4	1.11E+01	5.84E-01	4.10E-03	6.40E-02	2.02E+02	1.34E+03	No
64	38	1	1	1	4	1.11E+01	5.84E-01	2.74E-03	5.23E-02	9.69E+01	5.62E+02	No
64	40	1	1	1	4	9.14E+00	5.84E-01	5.47E-03	7.38E-02	5.25E+01	5.62E+02	No
64	47	1	1	0	4	1.89E+01	5.84E-01	1.37E-03	3.70E-02	7.55E+01	5.62E+02	No
64	51	1	1	1	4	9.14E+00	5.84E-01	6.84E-03	8.25E-02	3.79E+01	5.62E+02	No
64	52	1	1	0	4	1.89E+01	5.84E-01	1.37E-03	3.70E-02	4.57E+01	5.62E+02	No
64	53	1	1	1	4	1.11E+01	5.84E-01	2.74E-03	5.23E-02	8.08E+01	5.62E+02	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
65	**CW**	**1**	1	-1	10		2.13E+00	1.23E-02	2.10E-01			No
65	**19**	**1**	1	1	4	3.34E+01	2.13E+00	2.74E-03	5.23E-02	1.64E+02	6.58E+02	No
65	**42**	**1**	1	0	4	4.05E+01	2.13E+00	1.37E-03	3.70E-02	7.02E+00	6.58E+02	No
65	**43**	**1**	1	0	4	4.05E+01	2.13E+00	1.37E-03	3.70E-02	3.14E+01	6.58E+02	No
65	**47**	**1**	1	0	4	4.05E+01	2.13E+00	1.37E-03	3.70E-02	8.85E+01	6.58E+02	No
65	**51**	**1**	1	1	4	3.34E+01	2.13E+00	2.74E-03	5.23E-02	4.44E+01	6.58E+02	No
65	**52**	**1**	1	1	4	3.34E+01	2.13E+00	2.74E-03	5.23E-02	5.35E+01	6.58E+02	No
66	**CW**	**6**	2	-2	10		1.10E-02	2.74E-02	2.76E-01			No
66	**25**	**1**	1	1	4	2.18E+00	1.10E-02	1.37E-03	3.70E-02	3.48E+01	2.53E+02	No
66	**27**	**1**	1	3	4	2.18E+00	1.10E-02	2.74E-03	7.40E-02	1.55E+01	1.07E+02	No
66	**31**	**1**	1	3	4	2.18E+00	1.10E-02	2.74E-03	7.40E-02	2.65E+01	1.07E+02	No
66	**34**	**1**	1	1	4	2.18E+00	1.10E-02	1.37E-03	3.70E-02	1.56E+01	1.07E+02	No
66	**35**	**1**	1	1	4	2.18E+00	1.10E-02	1.37E-03	3.70E-02	3.38E+01	1.07E+02	No
66	**42**	**1**	1	3	4	2.18E+00	1.10E-02	2.74E-03	7.40E-02	1.14E+00	1.07E+02	No
66	**43**	**1**	1	3	4	2.18E+00	1.10E-02	2.74E-03	7.40E-02	5.12E+00	1.07E+02	No
66	**45**	**2**	1	1	4	2.18E+00	1.10E-02	5.47E-03	7.38E-02	2.78E+00	1.07E+02	No
66	**46**	**1**	1	3	4	2.18E+00	1.10E-02	2.74E-03	7.40E-02	5.35E+00	1.07E+02	No
66	**53**	**1**	1	3	4	2.18E+00	1.10E-02	4.10E-03	8.27E-02	1.54E+01	1.07E+02	No
67	**CW**	**3**	2	-1	15		1.28E-02	1.37E-02	1.48E-01			No
67	**13**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	1.22E+00	5.36E+00	No
67	**16**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	1.37E+00	5.36E+00	No
67	**29**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	6.38E-01	5.36E+00	No
67	**33**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	8.83E-01	5.36E+00	No
67	**34**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	7.80E-01	5.36E+00	No
67	**38**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	9.25E-01	5.36E+00	No
67	**42**	**1**	1	1	4	2.55E+00	1.28E-02	2.74E-03	5.23E-02	5.71E-02	5.36E+00	No
67	**43**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	2.56E-01	5.36E+00	No
67	**52**	**1**	1	1	4	2.55E+00	1.28E-02	1.37E-03	3.70E-02	4.36E-01	5.36E+00	No
68	**CW**	**4**	2	-1	15		6.79E-02	3.68E-02	3.66E-01			No
68	**16**	**1**	1	1	4	1.35E+01	6.79E-02	1.37E-03	3.70E-02	1.09E+00	4.29E+00	No
68	**41**	**1**	1	1	4	1.35E+01	6.79E-02	1.37E-03	3.70E-02	3.63E-01	4.29E+00	No
68	**42**	**1**	1	1	4	4.46E+00	6.79E-02	4.10E-03	6.40E-02	4.57E-02	4.29E+00	No
68	**45**	**1**	1	1	4	1.35E+01	6.79E-02	1.37E-03	3.70E-02	1.11E-01	4.29E+00	No
68	**51**	**2**	1	5	4	1.63E+00	6.79E-02	2.86E-02	3.31E-01	2.89E-01	4.29E+00	No
69	**CW**	**43**	4	-3	15		1.74E-02	7.04E-01	2.71E+00			No
69	**6**	**3**	2	14	4	3.46E+00	1.74E-02	1.37E-02	3.70E-01	1.65E+01	1.63E+02	Yes
69	**7**	**2**	1	11	4	8.51E-01	1.74E-02	2.05E-02	4.57E-01	1.99E+01	1.67E+02	Yes
69	**12**	**5**	2	13	4	4.17E-01	1.74E-02	8.89E-02	9.37E-01	1.31E+01	5.79E+01	No
69	**14**	**4**	2	8	4	4.17E-01	1.74E-02	7.23E-02	6.75E-01	1.56E+01	5.79E+01	No
69	**15**	**13**	2	15	4	2.72E-01	1.74E-02	3.16E-01	1.81E+00	1.35E+01	5.79E+01	No
69	**17**	**3**	2	6	4	5.62E-01	1.74E-02	4.24E-02	4.50E-01	1.48E+01	5.79E+01	No
69	**21**	**3**	2	9	4	8.51E-01	1.74E-02	3.01E-02	4.24E-01	1.16E+01	5.79E+01	No
69	**26**	**3**	2	8	4	5.62E-01	1.74E-02	4.10E-02	4.95E-01	2.08E+01	1.39E+02	No
69	**34**	**4**	2	9	4	4.79E-01	1.74E-02	5.61E-02	6.42E-01	8.42E+00	5.79E+01	No
69	**46**	**3**	1	5	4	8.51E-01	1.74E-02	2.33E-02	3.15E-01	2.89E+00	5.79E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
70	CW	31	4	-7	15		1.06E-02	3.99E-01	1.50E+00			No
70	5	5	2	10	4	2.11E+00	1.06E-02	2.60E-02	3.71E-01	2.24E+00	1.51E+01	Yes
70	18	4	2	5	4	6.97E-01	1.06E-02	3.83E-02	3.49E-01	1.49E+00	5.36E+00	No
70	21	5	2	5	4	2.11E+00	1.06E-02	2.60E-02	2.73E-01	1.07E+00	5.36E+00	No
70	22	7	2	7	4	2.93E-01	1.06E-02	9.67E-02	6.42E-01	9.39E-01	5.36E+00	No
70	24	4	2	4	4	6.97E-01	1.06E-02	3.56E-02	2.80E-01	8.34E-01	5.36E+00	No
70	25	1	1	5	4	2.11E+00	1.06E-02	4.10E-03	1.11E-01	1.74E+00	1.26E+01	No
70	26	2	1	3	4	2.11E+00	1.06E-02	5.47E-03	1.05E-01	1.93E+00	1.28E+01	No
70	27	6	2	8	4	2.93E-01	1.06E-02	8.47E-02	6.06E-01	7.74E-01	5.36E+00	No
70	32	5	2	9	4	5.20E-01	1.06E-02	4.51E-02	5.20E-01	1.20E+00	5.36E+00	No
70	35	4	2	6	4	6.97E-01	1.06E-02	3.69E-02	3.77E-01	1.69E+00	5.36E+00	No
71	CW	4	2	-1	14		6.61E-02	3.42E-02	3.17E-01			No
71	6	1	1	1	4	4.34E+00	6.61E-02	4.10E-03	6.40E-02	1.53E+01	1.51E+02	Yes
71	7	1	1	1	4	1.32E+01	6.61E-02	2.74E-03	5.23E-02	1.84E+01	1.54E+02	Yes
71	17	1	1	1	4	3.24E+00	6.61E-02	6.84E-03	8.25E-02	1.37E+01	5.36E+01	No
71	18	1	1	1	4	1.32E+01	6.61E-02	2.74E-03	5.23E-02	1.49E+01	5.36E+01	No
71	23	1	1	1	4	1.32E+01	6.61E-02	2.74E-03	5.23E-02	9.05E+00	5.36E+01	No
71	28	1	1	1	4	1.32E+01	6.61E-02	1.37E-03	3.70E-02	7.07E+00	5.36E+01	No
71	38	1	1	1	4	1.32E+01	6.61E-02	1.37E-03	3.70E-02	9.25E+00	5.36E+01	No
71	40	1	1	1	4	1.32E+01	6.61E-02	2.74E-03	5.23E-02	5.01E+00	5.36E+01	No
71	45	1	1	1	4	1.32E+01	6.61E-02	1.37E-03	3.70E-02	1.39E+00	5.36E+01	No
71	51	1	1	1	4	3.24E+00	6.61E-02	8.21E-03	9.03E-02	3.61E+00	5.36E+01	No
72	CW	3	2	-1	14		5.82E-02	2.19E-02	2.29E-01			No
72	6	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	3.06E+01	3.03E+02	Yes
72	13	1	1	1	4	1.16E+01	5.82E-02	2.74E-03	5.23E-02	2.45E+01	1.07E+02	No
72	16	1	1	3	4	1.16E+01	5.82E-02	2.74E-03	7.40E-02	2.73E+01	1.07E+02	No
72	22	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.88E+01	1.07E+02	No
72	35	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	3.38E+01	1.07E+02	No
72	38	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.85E+01	1.07E+02	No
72	40	1	1	1	4	1.16E+01	5.82E-02	1.37E-03	3.70E-02	1.00E+01	1.07E+02	No
72	42	1	1	1	4	2.85E+00	5.82E-02	6.84E-03	8.25E-02	1.14E+00	1.07E+02	No
72	51	1	1	1	4	1.16E+01	5.82E-02	2.74E-03	5.23E-02	7.22E+00	1.07E+02	No
73	CW	3	2	-1	14		1.16E-01	1.92E-02	2.14E-01			No
73	5	1	1	1	4	7.61E+00	1.16E-01	2.74E-03	5.23E-02	2.33E+01	1.57E+02	Yes
73	6	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	1.59E+01	1.57E+02	Yes
73	13	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	1.27E+01	5.58E+01	No
73	19	1	1	1	4	5.68E+00	1.16E-01	4.10E-03	6.40E-02	1.39E+01	5.58E+01	No
73	37	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	7.64E+00	5.58E+01	No
73	39	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	9.30E+00	5.58E+01	No
73	43	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	2.66E+00	5.58E+01	No
73	46	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	2.78E+00	5.58E+01	No
73	50	1	1	1	4	7.61E+00	1.16E-01	2.74E-03	5.23E-02	1.00E+01	5.58E+01	No
73	52	1	1	1	4	2.31E+01	1.16E-01	1.37E-03	3.70E-02	4.53E+00	5.58E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
74	CW	17	2	0	14		2.32E-02	2.16E-01	2.11E+00			No
74	1	3	1	24	4	7.52E-01	2.32E-02	3.97E-02	9.64E-01	5.15E+00	2.57E+01	Yes
74	3	2	1	2	4	4.63E+00	2.32E-02	9.58E-03	1.11E-01	4.29E+00	2.57E+01	Yes
74	6	2	1	1	4	4.63E+00	2.32E-02	6.84E-03	8.25E-02	2.60E+00	2.57E+01	Yes
74	12	1	1	1	4	4.63E+00	2.32E-02	1.37E-03	3.70E-02	2.06E+00	9.11E+00	No
74	22	1	1	1	4	4.63E+00	2.32E-02	2.74E-03	5.23E-02	1.60E+00	9.11E+00	No
74	24	5	1	37	4	4.42E-01	2.32E-02	8.21E-02	1.59E+00	1.42E+00	9.11E+00	No
74	26	2	1	4	4	4.63E+00	2.32E-02	5.47E-03	1.17E-01	3.27E+00	2.18E+01	No
74	28	3	1	11	4	1.14E+00	2.32E-02	2.74E-02	5.23E-01	1.20E+00	9.11E+00	No
74	42	3	1	18	4	7.52E-01	2.32E-02	3.28E-02	7.45E-01	9.71E-02	9.11E+00	No
74	53	2	1	1	4	4.63E+00	2.32E-02	8.21E-03	9.03E-02	1.31E+00	9.11E+00	No
75	CW	1	1	-1	14		2.46E-02	2.74E-03	5.23E-02			No
75	10	1	1	1	4	4.89E+00	2.46E-02	1.37E-03	3.70E-02	3.18E+00	2.72E+01	Yes
75	31	1	1	1	4	4.89E+00	2.46E-02	1.37E-03	3.70E-02	2.39E+00	9.65E+00	No
76	CW	5	2	-1	10		9.92E-03	2.46E-02	3.58E-01			Yes
76	42	2	2	7	4	1.97E+00	9.92E-03	6.84E-03	1.85E-01	8.00E-03	7.51E-01	No
76	43	4	2	7	4	1.97E+00	9.92E-03	1.78E-02	2.84E-01	3.58E-02	7.51E-01	No
77	CW	2	2	-1	10		7.77E-02	8.21E-03	1.37E-01			No
77	5	1	1	1	4	1.55E+01	7.77E-02	1.37E-03	3.70E-02	9.04E+00	6.11E+01	Yes
77	14	1	1	1	4	1.55E+01	7.77E-02	1.37E-03	3.70E-02	5.82E+00	2.17E+01	No
77	17	1	1	1	4	1.55E+01	7.77E-02	1.37E-03	3.70E-02	5.55E+00	2.17E+01	No
77	40	1	1	1	4	1.55E+01	7.77E-02	2.74E-03	5.23E-02	2.02E+00	2.17E+01	No
77	46	1	1	1	4	1.55E+01	7.77E-02	1.37E-03	3.70E-02	1.08E+00	2.17E+01	No
78	CW	6	2	-1	12		9.21E-04	2.60E-02	2.48E-01			No
78	4	1	1	4	4	1.83E-01	9.21E-04	4.10E-03	1.11E-01	2.11E-01	1.51E+00	Yes
78	9	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	2.14E-01	1.56E+00	Yes
78	12	1	1	2	4	1.83E-01	9.21E-04	4.10E-03	8.27E-02	1.21E-01	5.36E-01	No
78	13	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.22E-01	5.36E-01	No
78	14	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.44E-01	5.36E-01	No
78	16	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.37E-01	5.36E-01	No
78	21	2	1	5	4	1.83E-01	9.21E-04	5.47E-03	1.48E-01	1.07E-01	5.36E-01	No
78	26	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	1.93E-01	1.28E+00	No
78	35	1	1	4	4	1.83E-01	9.21E-04	4.10E-03	1.11E-01	1.69E-01	5.36E-01	No
78	53	1	1	1	4	1.83E-01	9.21E-04	1.37E-03	3.70E-02	7.71E-02	5.36E-01	No
79	CW	3	2	-1	12		1.21E-02	1.50E-02	1.43E-01			Yes
79	1	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	1.27E+00	6.36E+00	Yes
79	6	1	1	3	4	2.40E+00	1.21E-02	2.74E-03	7.40E-02	6.43E-01	6.36E+00	Yes
79	10	1	1	3	4	2.40E+00	1.21E-02	2.74E-03	7.40E-02	7.43E-01	6.36E+00	Yes
79	11	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	1.39E+00	6.64E+00	Yes
79	13	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	5.13E-01	2.25E+00	No
79	21	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	4.50E-01	2.25E+00	No
79	30	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	6.01E-01	2.25E+00	No
79	32	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	5.04E-01	2.25E+00	No
79	53	1	1	1	4	2.40E+00	1.21E-02	1.37E-03	3.70E-02	3.24E-01	2.25E+00	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
80	CW	17	3	-8	8		3.07E-02	2.39E-01	9.51E-01			No
80	4	2	1	1	4	6.12E+00	3.07E-02	6.84E-03	8.25E-02	3.13E+01	2.24E+02	Yes
80	7	2	1	1	4	2.02E+00	3.07E-02	1.09E-02	1.04E-01	2.73E+01	2.28E+02	Yes
80	18	3	1	2	4	8.48E-01	3.07E-02	3.69E-02	1.89E-01	2.20E+01	7.93E+01	No
80	22	3	1	2	4	8.48E-01	3.07E-02	3.97E-02	2.22E-01	1.39E+01	7.93E+01	No
80	25	3	1	2	4	8.48E-01	3.07E-02	3.42E-02	1.96E-01	2.58E+01	1.87E+02	No
80	33	2	1	2	4	2.02E+00	3.07E-02	1.92E-02	1.47E-01	1.31E+01	7.93E+01	No
80	35	3	1	2	4	8.48E-01	3.07E-02	3.28E-02	2.00E-01	2.50E+01	7.93E+01	No
80	40	2	1	1	4	2.02E+00	3.07E-02	1.23E-02	1.10E-01	7.41E+00	7.93E+01	No
80	50	2	1	1	4	2.02E+00	3.07E-02	1.50E-02	1.22E-01	1.42E+01	7.93E+01	No
80	52	3	1	1	4	8.48E-01	3.07E-02	3.15E-02	1.75E-01	6.45E+00	7.93E+01	No
81	CW	2	2	-1	8		9.49E-02	1.92E-02	2.60E-01			No
81	15	1	1	1	4	6.23E+00	9.49E-02	2.74E-03	5.23E-02	8.24E+00	3.53E+01	No
81	22	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	6.18E+00	3.53E+01	No
81	25	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	1.15E+01	8.31E+01	No
81	27	1	1	1	4	6.23E+00	9.49E-02	2.74E-03	5.23E-02	5.09E+00	3.53E+01	No
81	38	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	6.08E+00	3.53E+01	No
81	39	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	5.89E+00	3.53E+01	No
81	42	1	1	1	4	6.23E+00	9.49E-02	2.74E-03	5.23E-02	3.76E-01	3.53E+01	No
81	45	1	1	1	4	6.23E+00	9.49E-02	2.74E-03	5.23E-02	9.15E-01	3.53E+01	No
81	46	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	1.76E+00	3.53E+01	No
81	49	1	1	1	4	1.89E+01	9.49E-02	1.37E-03	3.70E-02	5.34E+00	3.53E+01	No
82	CW	2	2	-1	14		1.04E-01	1.23E-02	1.62E-01			No
82	10	1	1	1	4	6.82E+00	1.04E-01	2.74E-03	5.23E-02	5.64E+01	4.83E+02	Yes
82	28	1	1	2	4	6.82E+00	1.04E-01	2.74E-03	7.40E-02	2.26E+01	1.71E+02	No
82	40	1	1	1	4	2.07E+01	1.04E-01	1.37E-03	3.70E-02	1.60E+01	1.71E+02	No
82	42	1	1	2	4	6.82E+00	1.04E-01	2.74E-03	7.40E-02	1.82E+00	1.71E+02	No
82	49	1	1	1	4	2.07E+01	1.04E-01	1.37E-03	3.70E-02	2.59E+01	1.71E+02	No
82	50	1	1	1	4	2.07E+01	1.04E-01	1.37E-03	3.70E-02	3.07E+01	1.71E+02	No
83	CW	3	2	-1	10		1.96E-01	4.24E-02	3.88E-01			No
83	13	1	1	1	4	9.63E+00	1.96E-01	2.74E-03	5.23E-02	4.77E+00	2.09E+01	No
83	20	1	1	1	4	9.63E+00	1.96E-01	2.74E-03	5.23E-02	6.09E+00	2.09E+01	No
83	24	1	1	1	4	5.42E+00	1.96E-01	5.47E-03	7.38E-02	3.25E+00	2.09E+01	No
83	25	1	1	1	4	6.35E+00	1.96E-01	4.10E-03	6.40E-02	6.79E+00	4.93E+01	No
83	27	1	1	0	4	1.29E+01	1.96E-01	1.37E-03	3.70E-02	3.02E+00	2.09E+01	No
83	43	1	1	1	4	3.73E+00	1.96E-01	1.23E-02	1.10E-01	9.98E-01	2.09E+01	No
83	45	1	1	1	4	9.63E+00	1.96E-01	2.74E-03	5.23E-02	5.42E-01	2.09E+01	No
83	48	1	1	1	4	6.35E+00	1.96E-01	4.10E-03	6.40E-02	2.77E+00	2.09E+01	No
83	49	1	1	1	4	6.35E+00	1.96E-01	4.10E-03	6.40E-02	3.17E+00	2.09E+01	No
83	53	1	1	1	4	9.63E+00	1.96E-01	2.74E-03	5.23E-02	3.01E+00	2.09E+01	No
84	CW	1	1	-1	8		5.15E-02	2.74E-03	1.22E-01			No
84	44	1	1	1	4	1.02E+01	5.15E-02	2.74E-03	5.23E-02	8.42E+00	6.09E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
85	CW	8	2	-2	6		6.23E-03	4.10E-02	4.63E-01			No
85	3	2	2	9	4	1.24E+00	6.23E-03	8.21E-03	2.22E-01	1.31E+00	7.87E+00	Yes
85	14	1	1	3	4	1.24E+00	6.23E-03	2.74E-03	7.40E-02	7.49E-01	2.79E+00	No
85	31	1	1	3	4	1.24E+00	6.23E-03	2.74E-03	7.40E-02	6.90E-01	2.79E+00	No
85	32	1	1	3	4	1.24E+00	6.23E-03	2.74E-03	7.40E-02	6.24E-01	2.79E+00	No
85	39	1	1	1	4	1.24E+00	6.23E-03	2.74E-03	5.23E-02	4.65E-01	2.79E+00	No
85	49	2	1	6	4	1.24E+00	6.23E-03	5.47E-03	1.48E-01	4.22E-01	2.79E+00	No
85	50	4	2	10	4	1.24E+00	6.23E-03	1.64E-02	3.31E-01	5.00E-01	2.79E+00	No
86	CW	2	2	-1	6		4.41E-02	8.21E-03	1.59E-01			No
86	21	1	1	2	4	8.78E+00	4.41E-02	4.10E-03	8.27E-02	2.23E+00	1.12E+01	No
86	22	1	1	1	4	8.78E+00	4.41E-02	1.37E-03	3.70E-02	1.95E+00	1.12E+01	No
86	47	1	1	1	4	8.78E+00	4.41E-02	2.74E-03	5.23E-02	1.50E+00	1.12E+01	No
87	CW	7	2	-2	10		5.55E-03	3.15E-02	3.15E-01			No
87	4	1	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.69E-01	1.21E+00	Yes
87	5	1	1	3	4	1.10E+00	5.55E-03	2.74E-03	7.40E-02	1.79E-01	1.21E+00	Yes
87	8	3	2	6	4	1.10E+00	5.55E-03	1.23E-02	2.12E-01	1.36E-01	1.23E+00	Yes
87	13	1	1	1	4	1.10E+00	5.55E-03	2.74E-03	5.23E-02	9.78E-02	4.29E-01	No
87	16	1	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.09E-01	4.29E-01	No
87	19	1	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	1.07E-01	4.29E-01	No
87	25	1	1	3	4	1.10E+00	5.55E-03	4.10E-03	8.27E-02	1.39E-01	1.01E+00	No
87	32	1	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	9.59E-02	4.29E-01	No
87	33	1	1	1	4	1.10E+00	5.55E-03	2.74E-03	5.23E-02	7.06E-02	4.29E-01	No
87	53	1	1	1	4	1.10E+00	5.55E-03	1.37E-03	3.70E-02	6.16E-02	4.29E-01	No
88	CW	4	2	-1	10		2.57E-02	1.78E-02	2.37E-01			No
88	6	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.66E+01	1.64E+02	Yes
88	9	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	2.32E+01	1.70E+02	Yes
88	10	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.92E+01	1.64E+02	Yes
88	19	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.45E+01	5.81E+01	No
88	31	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	1.44E+01	5.81E+01	No
88	47	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	7.81E+00	5.81E+01	No
88	52	2	1	1	4	5.12E+00	2.57E-02	8.21E-03	9.03E-02	4.73E+00	5.81E+01	No
88	53	1	1	1	4	5.12E+00	2.57E-02	1.37E-03	3.70E-02	8.35E+00	5.81E+01	No
89	CW	9	2	-2	10		1.91E-03	4.24E-02	2.91E-01			No
89	11	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	1.33E-01	6.32E-01	Yes
89	13	2	1	3	4	3.81E-01	1.91E-03	5.47E-03	1.05E-01	4.89E-02	2.14E-01	No
89	25	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	6.97E-02	5.05E-01	No
89	29	2	2	3	4	3.81E-01	1.91E-03	8.21E-03	1.28E-01	2.55E-02	2.14E-01	No
89	31	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	5.31E-02	2.14E-01	No
89	37	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.94E-02	2.14E-01	No
89	42	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.29E-03	2.14E-01	No
89	47	1	1	3	4	3.81E-01	1.91E-03	2.74E-03	7.40E-02	2.88E-02	2.14E-01	No
89	48	2	1	3	4	3.81E-01	1.91E-03	6.84E-03	1.11E-01	2.84E-02	2.14E-01	No
89	53	2	1	3	4	3.81E-01	1.91E-03	5.47E-03	1.05E-01	3.08E-02	2.14E-01	No
90	CW	1	1	-1	10		6.60E-03	1.37E-03	3.70E-02			Yes
90	43	1	1	1	4	1.31E+00	6.60E-03	1.37E-03	3.70E-02	6.30E+00	1.32E+02	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
91	**CW**	**7**	2	-2	10		2.01E-02	3.15E-02	3.91E-01			No
91	**6**	**2**	1	1	4	4.01E+00	2.01E-02	5.47E-03	7.38E-02	8.57E-01	8.47E+00	Yes
91	**9**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	1.20E+00	8.76E+00	Yes
91	**16**	**3**	1	1	4	4.01E+00	2.01E-02	1.37E-02	1.16E-01	7.65E-01	3.00E+00	No
91	**17**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	7.69E-01	3.00E+00	No
91	**18**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	8.34E-01	3.00E+00	No
91	**24**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	4.67E-01	3.00E+00	No
91	**25**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	9.75E-01	7.07E+00	No
91	**34**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	4.37E-01	3.00E+00	No
91	**45**	**1**	1	1	4	4.01E+00	2.01E-02	2.74E-03	5.23E-02	7.79E-02	3.00E+00	No
91	**51**	**1**	1	1	4	4.01E+00	2.01E-02	1.37E-03	3.70E-02	2.02E-01	3.00E+00	No
92	**CW**	**1**	2	-1	10		3.42E-02	4.10E-03	1.21E-01			Yes
92	**24**	**1**	1	1	4	6.80E+00	3.42E-02	1.37E-03	3.70E-02	4.34E+00	2.79E+01	No
92	**53**	**1**	1	1	4	6.80E+00	3.42E-02	2.74E-03	5.23E-02	4.01E+00	2.79E+01	No
93	**CW**	**20**	3	-8	10		3.54E-02	3.42E-01	1.05E+00			No
93	**4**	**3**	1	2	4	8.50E-01	3.54E-02	4.65E-02	2.11E-01	1.69E+01	1.21E+02	Yes
93	**5**	**4**	1	2	4	6.73E-01	3.54E-02	6.16E-02	2.57E-01	1.79E+01	1.21E+02	Yes
93	**8**	**3**	1	1	4	9.77E-01	3.54E-02	3.69E-02	1.89E-01	1.36E+01	1.23E+02	Yes
93	**12**	**3**	1	2	4	9.77E-01	3.54E-02	3.97E-02	2.09E-01	9.70E+00	4.29E+01	No
93	**16**	**3**	1	2	4	9.77E-01	3.54E-02	3.28E-02	1.86E-01	1.09E+01	4.29E+01	No
93	**18**	**2**	1	2	4	1.74E+00	3.54E-02	1.50E-02	1.33E-01	1.19E+01	4.29E+01	No
93	**20**	**3**	1	1	4	9.77E-01	3.54E-02	3.56E-02	1.85E-01	1.25E+01	4.29E+01	No
93	**23**	**3**	1	2	4	9.77E-01	3.54E-02	3.28E-02	1.86E-01	7.24E+00	4.29E+01	No
93	**34**	**3**	1	2	4	9.77E-01	3.53E-02	3.42E-02	1.89E-01	6.24E+00	4.29E+01	No
93	**38**	**1**	1	2	4	2.33E+00	3.53E-02	6.84E-03	9.77E-02	7.40E+00	4.29E+01	No
94	**CW**	**18**	3	1	15		3.90E-02	2.90E-01	1.66E+00			No
94	**10**	**4**	1	10	4	7.42E-01	3.90E-02	7.50E-02	8.09E-01	4.95E+00	4.24E+01	Yes
94	**13**	**2**	1	5	4	1.91E+00	3.90E-02	1.37E-02	2.67E-01	3.42E+00	1.50E+01	No
94	**15**	**3**	1	15	4	7.42E-01	3.90E-02	4.38E-02	8.38E-01	3.51E+00	1.50E+01	No
94	**18**	**2**	1	11	4	9.37E-01	3.90E-02	3.96E-02	5.65E-01	4.17E+00	1.50E+01	No
94	**19**	**2**	1	11	4	1.91E+00	3.90E-02	1.64E-02	4.44E-01	3.74E+00	1.50E+01	No
94	**22**	**2**	1	7	4	1.91E+00	3.90E-02	1.64E-02	3.31E-01	2.63E+00	1.50E+01	No
94	**31**	**2**	1	9	4	1.91E+00	3.90E-02	1.37E-02	3.70E-01	3.71E+00	1.50E+01	No
94	**35**	**3**	1	8	4	7.42E-01	3.90E-02	4.37E-02	5.86E-01	4.73E+00	1.50E+01	No
94	**49**	**2**	1	7	4	1.26E+00	3.90E-02	2.19E-02	4.18E-01	2.27E+00	1.50E+01	No
94	**51**	**2**	1	5	4	7.77E+00	3.90E-02	5.47E-03	1.48E-01	1.01E+00	1.50E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
95	CW	31	3	-3	15		5.54E-03	2.91E-01	2.22E+00			No
95	14	8	2	27	4	2.71E-01	5.54E-03	7.39E-02	1.31E+00	1.44E+00	5.36E+00	No
95	17	2	2	7	4	1.10E+00	5.54E-03	6.84E-03	1.85E-01	1.37E+00	5.36E+00	No
95	24	6	2	24	4	2.71E-01	5.54E-03	6.16E-02	1.09E+00	8.34E-01	5.36E+00	No
95	27	8	2	17	4	1.10E+00	5.54E-03	3.97E-02	6.45E-01	7.74E-01	5.36E+00	No
95	29	2	1	6	4	1.10E+00	5.54E-03	5.47E-03	1.48E-01	6.38E-01	5.36E+00	No
95	35	9	2	20	4	1.10E+00	5.54E-03	4.79E-02	7.62E-01	1.69E+00	5.36E+00	No
95	37	3	2	7	4	1.10E+00	5.54E-03	1.50E-02	2.48E-01	7.35E-01	5.36E+00	No
95	45	6	2	30	4	1.10E+00	5.54E-03	2.74E-02	7.40E-01	1.39E-01	5.36E+00	No
95	48	3	2	15	4	1.10E+00	5.54E-03	1.37E-02	3.70E-01	7.11E-01	5.36E+00	No
96	CW	12	3	-3	10		1.37E-01	3.21E-01	9.54E-01			No
96	5	2	1	1	4	2.10E+00	1.34E-01	4.92E-02	2.23E-01	2.06E+01	1.40E+02	Yes
96	9	2	1	1	4	2.55E+00	1.34E-01	2.19E-02	1.46E-01	1.97E+01	1.44E+02	Yes
96	10	2	1	1	4	2.55E+00	1.34E-01	2.74E-02	1.63E-01	1.63E+01	1.40E+02	Yes
96	14	1	1	1	4	3.70E+00	1.34E-01	6.84E-03	8.25E-02	1.33E+01	4.94E+01	No
96	20	1	1	1	4	3.22E+00	1.38E-01	8.21E-03	9.03E-02	1.44E+01	4.94E+01	No
96	26	2	1	1	4	2.55E+00	1.34E-01	2.87E-02	1.67E-01	1.78E+01	1.18E+02	No
96	27	3	1	1	4	2.10E+00	1.36E-01	5.19E-02	2.28E-01	7.13E+00	4.94E+01	No
96	34	2	1	1	4	2.10E+00	1.36E-01	3.28E-02	1.86E-01	7.19E+00	4.94E+01	No
96	42	4	1	2	4	2.10E+00	1.52E-01	8.21E-02	2.80E-01	5.27E-01	4.94E+01	No
96	50	1	1	1	4	3.22E+00	1.34E-01	1.23E-02	1.22E-01	8.87E+00	4.94E+01	No
97	CW	3	2	-1	10		2.26E-03	1.50E-02	1.73E-01			No
97	19	2	1	3	4	4.50E-01	2.26E-03	6.84E-03	1.11E-01	2.67E-01	1.07E+00	No
97	21	1	1	3	4	4.50E-01	2.26E-03	2.74E-03	7.40E-02	2.14E-01	1.07E+00	No
97	22	1	1	3	4	4.50E-01	2.26E-03	2.74E-03	7.40E-02	1.88E-01	1.07E+00	No
97	52	1	1	3	4	4.50E-01	2.26E-03	2.74E-03	7.40E-02	8.72E-02	1.07E+00	No
98	CW	4	2	-2	10		9.52E-02	3.01E-02	3.32E-01			Yes
98	1	1	1	1	4	1.90E+01	9.52E-02	1.37E-03	3.70E-02	1.09E+01	5.45E+01	Yes
98	2	1	1	1	4	1.90E+01	9.52E-02	1.37E-03	3.70E-02	9.69E+00	5.75E+01	Yes
98	3	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	9.08E+00	5.45E+01	Yes
98	4	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	7.61E+00	5.45E+01	Yes
98	10	1	1	1	4	3.08E+00	9.52E-02	8.21E-03	9.03E-02	6.36E+00	5.45E+01	Yes
98	16	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	4.92E+00	1.93E+01	No
98	18	1	1	1	4	4.67E+00	9.52E-02	4.10E-03	6.40E-02	5.36E+00	1.93E+01	No
98	20	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	5.62E+00	1.93E+01	No
98	27	1	1	1	4	1.90E+01	9.52E-02	1.37E-03	3.70E-02	2.79E+00	1.93E+01	No
98	36	1	1	1	4	6.25E+00	9.52E-02	2.74E-03	5.23E-02	3.88E+00	1.93E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
99	**CW**	**25**	2	-4	10		2.66E-04	1.27E-01	1.12E+00			No
99	**15**	**4**	2	9	4	5.30E-02	2.66E-04	1.92E-02	3.18E-01	2.51E-01	1.07E+00	No
99	**20**	**1**	1	3	4	5.30E-02	2.66E-04	2.74E-03	7.40E-02	3.12E-01	1.07E+00	No
99	**29**	**6**	2	29	4	5.30E-02	2.66E-04	3.01E-02	7.43E-01	1.28E-01	1.07E+00	No
99	**31**	**3**	2	8	4	5.30E-02	2.66E-04	1.37E-02	2.61E-01	2.65E-01	1.07E+00	No
99	**33**	**2**	2	7	4	5.30E-02	2.66E-04	6.84E-03	1.85E-01	1.77E-01	1.07E+00	No
99	**34**	**3**	2	11	4	5.30E-02	2.66E-04	1.09E-02	2.96E-01	1.56E-01	1.07E+00	No
99	**37**	**2**	1	3	4	5.30E-02	2.66E-04	5.47E-03	1.05E-01	1.47E-01	1.07E+00	No
99	**42**	**2**	2	7	4	5.30E-02	2.66E-04	6.84E-03	1.85E-01	1.14E-02	1.07E+00	No
99	**46**	**1**	1	1	4	5.30E-02	2.66E-04	1.37E-03	3.70E-02	5.35E-02	1.07E+00	No
99	**47**	**6**	2	15	4	5.30E-02	2.66E-04	3.01E-02	5.25E-01	1.44E-01	1.07E+00	No
100	**CW**	**5**	2	-2	10		4.41E-03	2.19E-02	2.93E-01			No
100	**6**	**2**	1	1	4	8.77E-01	4.41E-03	5.47E-03	7.38E-02	3.06E-01	3.03E+00	Yes
100	**8**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	3.41E-01	3.08E+00	Yes
100	**13**	**1**	1	1	4	8.77E-01	4.41E-03	2.74E-03	5.23E-02	2.45E-01	1.07E+00	No
100	**22**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.88E-01	1.07E+00	No
100	**24**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.67E-01	1.07E+00	No
100	**25**	**1**	1	1	4	8.77E-01	4.41E-03	2.74E-03	5.23E-02	3.48E-01	2.53E+00	No
100	**26**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	3.85E-01	2.57E+00	No
100	**37**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
100	**52**	**1**	1	1	4	8.77E-01	4.41E-03	1.37E-03	3.70E-02	8.72E-02	1.07E+00	No
100	**53**	**1**	1	1	4	8.77E-01	4.41E-03	2.74E-03	5.23E-02	1.54E-01	1.07E+00	No
101	**CW**	**4**	2	-1	10		3.38E-03	1.78E-02	2.01E-01			No
101	**4**	**1**	1	1	4	6.73E-01	3.38E-03	2.74E-03	5.23E-02	4.23E-02	3.03E-01	Yes
101	**6**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	3.06E-02	3.03E-01	Yes
101	**9**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	4.27E-02	3.13E-01	Yes
101	**13**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.45E-02	1.07E-01	No
101	**15**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.51E-02	1.07E-01	No
101	**32**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	2.40E-02	1.07E-01	No
101	**38**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.85E-02	1.07E-01	No
101	**44**	**1**	1	1	4	6.73E-01	3.38E-03	4.10E-03	6.40E-02	1.48E-02	1.07E-01	No
101	**49**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.62E-02	1.07E-01	No
101	**50**	**1**	1	1	4	6.73E-01	3.38E-03	1.37E-03	3.70E-02	1.92E-02	1.07E-01	No
102	**CW**	**3**	2	-1	10		2.55E-02	1.50E-02	1.69E-01			No
102	**5**	**2**	1	3	4	5.08E+00	2.55E-02	5.47E-03	1.05E-01	8.91E+00	6.02E+01	Yes
102	**7**	**1**	1	3	4	5.08E+00	2.55E-02	2.74E-03	7.40E-02	7.34E+00	6.14E+01	Yes
102	**11**	**1**	1	3	4	5.08E+00	2.55E-02	2.74E-03	7.40E-02	1.32E+01	6.29E+01	Yes
102	**31**	**1**	1	1	4	5.08E+00	2.55E-02	1.37E-03	3.70E-02	5.28E+00	2.13E+01	No
102	**50**	**1**	1	3	4	5.08E+00	2.55E-02	2.74E-03	7.40E-02	3.83E+00	2.13E+01	No

Appendix J

Item nbr	Warehouse Nbr	Q	R Single-echelon	R Multi-echelon	L	p	h	mean demand	std of demand	CO2-emissions (g) per normal item	CO2-emissions (g) per emergency item	Emergency orders by Air?
103	**CW**	**3**	2	-1	10		4.46E-02	1.37E-02	1.17E-01			Yes
103	**1**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	2.00E+01	9.99E+01	Yes
103	**2**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.78E+01	1.05E+02	Yes
103	**6**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.01E+01	9.99E+01	Yes
103	**7**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.22E+01	1.02E+02	Yes
103	**11**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	2.19E+01	1.04E+02	Yes
103	**20**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.03E+01	3.54E+01	No
103	**25**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	1.15E+01	8.34E+01	No
103	**30**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	9.45E+00	3.54E+01	No
103	**31**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	8.75E+00	3.54E+01	No
103	**40**	**1**	1	1	4	8.87E+00	4.46E-02	1.37E-03	3.70E-02	3.30E+00	3.54E+01	No
104	**CW**	**4**	2	-1	10		4.67E-02	3.15E-02	3.09E-01			Yes
104	**4**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	9.72E+00	6.96E+01	Yes
104	**7**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	8.48E+00	7.10E+01	Yes
104	**9**	**1**	1	1	4	9.30E+00	4.67E-02	1.37E-03	3.70E-02	9.83E+00	7.19E+01	Yes
104	**10**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	8.13E+00	6.96E+01	Yes
104	**24**	**1**	1	1	4	9.30E+00	4.67E-02	1.37E-03	3.70E-02	3.84E+00	2.47E+01	No
104	**43**	**1**	1	2	4	2.29E+00	4.67E-02	9.58E-03	1.33E-01	1.18E+00	2.47E+01	No
104	**46**	**1**	1	1	4	9.30E+00	4.67E-02	1.37E-03	3.70E-02	1.23E+00	2.47E+01	No
104	**50**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	4.42E+00	2.47E+01	No
104	**51**	**1**	1	2	4	9.30E+00	4.67E-02	4.10E-03	8.26E-02	1.66E+00	2.47E+01	No
104	**52**	**1**	1	1	4	9.30E+00	4.67E-02	2.74E-03	5.23E-02	2.01E+00	2.47E+01	No
105	**CW**	**5**	2	-2	10		2.19E-02	2.19E-02	2.80E-01			No
105	**1**	**1**	1	3	4	4.35E+00	2.19E-02	2.74E-03	7.40E-02	6.05E-01	3.03E+00	Yes
105	**8**	**2**	1	1	4	4.35E+00	2.19E-02	5.47E-03	7.38E-02	3.41E-01	3.08E+00	Yes
105	**13**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.45E-01	1.07E+00	No
105	**17**	**1**	1	1	4	4.35E+00	2.19E-02	2.74E-03	5.23E-02	2.75E-01	1.07E+00	No
105	**19**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.67E-01	1.07E+00	No
105	**23**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	1.81E-01	1.07E+00	No
105	**30**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	2.86E-01	1.07E+00	No
105	**34**	**1**	1	1	4	4.35E+00	2.19E-02	2.74E-03	5.23E-02	1.56E-01	1.07E+00	No
105	**37**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	1.47E-01	1.07E+00	No
105	**43**	**1**	1	1	4	4.35E+00	2.19E-02	1.37E-03	3.70E-02	5.12E-02	1.07E+00	No
106	**CW**	**2**	2	-1	10		4.59E-03	9.58E-03	1.51E-01			No
106	**12**	**1**	1	3	4	9.13E-01	4.59E-03	2.74E-03	7.40E-02	2.42E-01	1.07E+00	No
106	**27**	**1**	1	1	4	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.55E-01	1.07E+00	No
106	**29**	**1**	1	1	4	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.28E-01	1.07E+00	No
106	**42**	**1**	1	1	4	9.13E-01	4.59E-03	2.74E-03	5.23E-02	1.14E-02	1.07E+00	No
106	**47**	**1**	1	1	4	9.13E-01	4.59E-03	1.37E-03	3.70E-02	1.44E-01	1.07E+00	No