Creation of a Simulation Model based upon Process Mapping within Pipeline Management at Scania

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Niklas Stadler

Master’s Thesis LIU-IEI-TEK-A--13/01671--SE
Department of Management and Engineering
Logistics Management
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Abstract
This is a Master’s Thesis that has been carried out at the Global Outbound Logistics department at Scania. Scania manufactures trucks, buses and engines. Some trucks and buses are delivered to markets where it, due to reduced customs duties and cheaper manpower, is more profitable to do the assembly locally at so called Regional Product Centres (RPCs). Since the components are produced far away from the RPC markets the lead times become long. In addition, the customers’ buying behaviour at the RPC markets is often not comparable to the European culture were a customer can accept to wait for weeks for a unit to be delivered. The long lead time in combination with the customer behaviour implies that the RPCs need to keep a certain selection of standard models of buses and trucks in stock. It has turned out to be difficult for the pipeline managers at the RPCs to place order volumes that correspond well to what will be delivered to the business units or distributors later on. The result of this is high stock levels at the RPCs, which leads to an important amount of tied up capital.

Due to what is explained above, the purpose of this study is “to create a simulation model, based upon a process mapping, that visualises future volume levels in the pipeline due to different demand and ordering scenarios”. The short term target, which is also the target of this study, is to increase the RPCs understanding for how different demand and ordering scenarios influence the future volume levels in the pipeline. The long term target is to reduce tied up capital by adjusting buffer levels and lead times, while still ensuring a certain service level. The model should contribute to more accurate decision making with respect to the previous mentioned aspects.

First, a high level process mapping was made in order to select which flows that were suitable for being subject for a detailed mapping. Second, a detailed mapping was made during which several RPC-, process- and function responsible were interviewed. After the detailed mapping, common denominators between the flows were identified and all activities were clustered into a solution that could be generalised and suitable for all flows. Factors such as lead times, deviation risks and capacity limitations were taken into account during the aggregation of activities.

When a common view of the different RPC flows had been created, the mathematical relationships for how the goods can move throughout the process could be established. Then, the development and validation of the simulation model, which was an iterative process, could start. A directive was to build the simulation model in Microsoft Excel. Interviews were made with experienced model creators in order to find out how to create a user-friendly and robust model. The creation of the simulation model started with the development of a structure and then the content of each part was defined. A final validation, which consisted of sensitivity analysis and user trials, was finally done in order to ensure the simulation models functioning and accuracy.

To conclude, a simulation model that will serve as a helpful tool for the RPCs when they are to decide which order volumes to place has been created. By clearly visualising the simulation results, the simulation model will hopefully increase the RPCs’ comprehension for how the pipeline works with respect to different ordering and demand scenarios.

On top of this, the method used, the process mapping and the mathematical relationships that have been defined are important input for a possible future development of a more permanent and robust non-Microsoft Excel solution. This solution could probably be even more precise, automatically updated and have an even higher granularity.
Foreword
This Master’s Thesis has been carried out during spring 2013 as a final part of the programme Industrial Engineering and Management at Linköping University (LiU). The topic originates from the Global Outbound Logistics (MDO) department at Scania. This department, and the Department of Management and Engineering (IEI) at Linköping University have supported us throughout the study.

Numerous persons have been involved in the study along the road towards its final output and we would like to thank all of them. However, some persons deserve special thanks.

To begin with, Annmari Balázs, pipeline manager and our supervisor at Scania, has been very supportive, willing to help out in many situations and a fantastic source of information. She has also contributed to a nice working environment and a good atmosphere. Hans Ekman, manager at MDO, has also provided valuable information and he has often put the problem into a bigger picture during the weekly meetings we have had, something we have appreciated a lot.

Next, we would like to thank Christina Maack, doctoral student and our supervisor at LiU. Christina has frequently guided us through our work, returned feedback on our performance and motivated us during the study. It has been a pleasure to have Christina as supervisor. We have also received important input and from professor Mats Abrahamsson and lecturer Fredrik Stahre who also work at LiU and who are very experienced in the logistics area.

Our opponents, Therése Tholin and Klara Södergren, have given us excellent advices and shared their reflections upon our work.

We also want to thank everybody who has taken the time to get interviewed by us. Your answers have been an essential component in the study.

Finally, we want to thank all of our nice colleagues at the MDO office.

Linköping, 5th of June 2013

Elin Ovesson
Niklas Stadler

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1 Introduction

In this chapter a brief presentation of Scania is given and then an explanation to the background of the problem, that is source to the study, is presented. As a result of the problem background, a purpose for this study is elaborated and specified. In order to clarify what is included in the study and what is not, received directives and chosen delimitations are presented. The final section of the chapter points out the target groups of the study’s output and shows the structure of the report.
1 Introduction

1.1 **Wordlist**

Below, Scania specific terms and general abbreviations are listed. Terms of a more theoretical nature are defined in deep in chapter 2 Theoretical Framework while the others are defined where they first appear in the report.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation</td>
<td>Additional special equipment that is added to a finished vehicle, and that a customer has asked for, in order to make it suitable for certain kinds of use or preferences.</td>
</tr>
<tr>
<td>ADD</td>
<td>Actual Delivery Date</td>
</tr>
<tr>
<td>Body Building</td>
<td>When a body is built on a bus or truck chassis, e.g. a tipper or a mixer that is built on a truck chassis.</td>
</tr>
<tr>
<td>BU/distributor</td>
<td>Business Unit/distributor</td>
</tr>
<tr>
<td>CBU</td>
<td>Completely Built Unit</td>
</tr>
<tr>
<td>CKD</td>
<td>Complete Knock Down</td>
</tr>
<tr>
<td>Components</td>
<td>Components are products that are assemblies of several parts, such as gearboxes, axles, engines and cabs.</td>
</tr>
<tr>
<td>Component PRU</td>
<td>A PRU producing components</td>
</tr>
<tr>
<td>COW</td>
<td>Central Orders on the Web (a Scania application)</td>
</tr>
<tr>
<td>CRD</td>
<td>Confirmed Release Date</td>
</tr>
<tr>
<td>ETA</td>
<td>Estimated Time of Arrival</td>
</tr>
<tr>
<td>FAIN</td>
<td>Factory Availability Indication (a Scania application)</td>
</tr>
<tr>
<td>FFU</td>
<td>Fit For Use</td>
</tr>
<tr>
<td>F&amp;F</td>
<td>Franchise and Factory sales (a Scania department)</td>
</tr>
<tr>
<td>FGI</td>
<td>Finished Goods Inventory</td>
</tr>
<tr>
<td>GOLS</td>
<td>Global Outbound Logistics Solution</td>
</tr>
<tr>
<td>IACOB</td>
<td>Integration &amp; Common Order Book (a Scania application)</td>
</tr>
<tr>
<td>KD</td>
<td>Knock Down</td>
</tr>
<tr>
<td>KDFU</td>
<td>KD-Follow-UP</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>KKXV</td>
<td>Volume Planning (a Scania department)</td>
</tr>
<tr>
<td>Non-Refill Units/Vehicles</td>
<td>Vehicles that are customer specific and not kept in stock.</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>MDO</td>
<td>Global Outbound Logistics (a Scania department)</td>
</tr>
<tr>
<td>MTO</td>
<td>Make-To-Order</td>
</tr>
<tr>
<td>MTS</td>
<td>Make-To-Stock</td>
</tr>
<tr>
<td>OPP</td>
<td>Order Penetration Point</td>
</tr>
<tr>
<td>P&amp;L</td>
<td>Production and Logistics (a Scania department)</td>
</tr>
<tr>
<td>Parts</td>
<td>All articles used when building a component or assembling a chassis, e.g. nuts, bolts, O-rings and forged units. The parts cannot be further broken down by disassembly.</td>
</tr>
<tr>
<td>PSA</td>
<td>Product/Service Agreement</td>
</tr>
<tr>
<td>PDI</td>
<td>Pre Delivery Inspection</td>
</tr>
<tr>
<td>PRU</td>
<td>Production Unit</td>
</tr>
<tr>
<td>Refill Units/Refill Vehicles</td>
<td>A limited number of standardised vehicle models that have been selected to always be in stock at the RPCs. These vehicles can be delivered to the customer within a short timeframe.</td>
</tr>
<tr>
<td>RPC</td>
<td>Regional Product Centre</td>
</tr>
<tr>
<td>S&amp;OP</td>
<td>Sales and Operations Planning</td>
</tr>
<tr>
<td>S&amp;S</td>
<td>Sales and Services (a Scania department)</td>
</tr>
<tr>
<td>SOLEIL</td>
<td>Scania Outbound Logistics Exchange Information on Line (a Scania application)</td>
</tr>
<tr>
<td>SKD</td>
<td>Semi Knock Down</td>
</tr>
<tr>
<td>Sub-assemblies</td>
<td>Several parts assembled together but not into something as big as a component. A radiator is an example of a sub-assembly.</td>
</tr>
<tr>
<td>SWIP</td>
<td>Scania Web Information Provider (a Scania application)</td>
</tr>
</tbody>
</table>
1 Introduction

1.2 COMPANY PRESENTATION

1.2.1 Briefly about Scania

History
A company named Vagnsfabriksaktiebolaget i Södertelge, Vabis, was founded in 1891. Nine years later, Maskinfabriksaktiebolaget Scania started its production of bicycles. In 1911, these two companies merged into one and Scania-Vabis was created. Until this day, Vabis had produced more than 3,000 railroad cars and Sweden’s first automobile. Both Vabis and Scania had manufactured trucks since 1902 but the two rivals decided to become one to remain powerful due to the increasing competition in Europe. Scania-Vabis was still constructing automobiles, trucks and buses but the production of bicycles and railroad cars ended with the fusion. (Scania, 2011)

During the first half of the 20th century Scania-Vabis became a solid company with skilled workers and a strong financial situation. In the 1950s, the first production plant outside Södertälje, Sweden, was established. Since Brazil had become an important market, especially for heavy trucks, it was natural to use a plant outside São Paulo as a basis for the Latin American production. In 1964, a plant in Zwolle in the Netherlands was established due to the success on the Dutch market. During the second half of the 1900s Scania-Vabis merged with Saab and became Saab-Scania, a cooperation that lasted for 26 years. In 1995, Saab-Scania separated and Scania became an autonomous company again. In 1996, Scania was introduced on the stock exchange and became Scania CV AB (from now on Scania). During the last decade, Volkswagen AB has bought an important amount of shares in Scania, which means that they have the lead ownership responsibility in the company. (Scania, 2011; Scania 2013a)

Scania Today
Today, Scania is represented in more than 100 countries around the globe and has about 1,600 service points offering service and support. The company has its headquarter in Södertälje where, beside the head office, functions such as sales and services, purchasing, production and logistics and research and development are situated. In total, Scania has approximately 37,500 employees. (Scania, 2013a)

During 2011, Scania had a total turnover of 90,309 billion SEK and a net result of 9,369 billion SEK. The company delivered 72,120 trucks and 7,988 buses, an increase in total deliveries compared to 2010 by 25 per cent. (Scania, 2012)

Since 2012, Scania’s President and CEO is Martin Lundstedt who superseded Leif Östling after 18 years in this position (Scania, 2013a). In Figure 1, Scania’s organisational structure is presented. The boxes in the organisational chart that are darker are all presented more in detail below.
1.2.2 Production and Logistics – P&L
The department Production and Logistics (from now on P&L) is divided into six sub departments; Industrial Control, Production Control, Chassis and Cab Production, Human Resources, SPS & Industrial Development and Powertrain Production. The Industrial Control department includes economic functions such as accounting and controlling, while the Production Control department works with order logistics and central planning. The SPS & Industrial Development department develop standard ways of working within the production and logistics area. (Scania, 2013b)

1.2.3 Chassis and Cab Production – M
The Chassis and Cab Production (from now on M) consists among others of production in Södertälje, Angers in France and Meppel and Zwolle in the Netherlands. The chassis assembly is located in Södertälje, Zwolle and Angers and the cab assembly in Oskarshamn in Sweden. As mentioned above, the Chassis and Cab Production includes several production and assembly sites but the global P&L organisation operates as one unit to achieve economies of scale. This means that all production and assembly sites use the same methods and processes to increase flexibility and reach higher productivity. (Scania, 2013b)

1.2.4 Regional Product Centres – MD
The sub department Regional Product Centres (from now on MD) is a part of the Chassis and Cab Production department.

“MD’s mission is to continuously move the factory gate closer to the Customer. By taking care of production and logistic after factory activities, MD shall help Scania business units to focus on their S&S core business. By applying industrial and logistic knowledge in these operations contributing to a more profitable Scania” (Scania, 2013c)

These production sites within MD are also called Regional Product Centres (from now on RPC). Further on in the report, when referring to Regional Product Centres or RPCs, the physical production sites are denoted and not the sub department.

1 S&S refers to Sales and Services Management
1 Introduction

In Figure 2, a breakdown of the MD organisation is depicted. What is not visible on the organisation chart is that MDA includes the RPC in Thailand as well as the one in Malaysia. They are one organisational department but two RPC units.

![Organisational Structure MD](image)

Figure 2. Organisational Structure MD

1.2.5 Global Outbound Logistics – MDO

The mission of MDO, which is stated below, describes somewhat the role of the department.

“The MDO mission is to establish, improve, support and be the owner of the methods and tools for global outbound product logistics.” (Scania, 2013c)

Global Outbound Logistics (from now on MDO) strives for high quality and delivery precision as well as reduction of costs, lead time and tied up capital. MDO owns the following processes: outbound transports, pipeline management and complete vehicles. MDO conducts process development, follow-up and supports the RPCs. Even if the RPCs make their own follow-up, they report to MDO who makes the performance measurement regarding key performance indicators. Furthermore, MDO develops common ways of working and provides the RPCs with tools to increase their efficiency and effectiveness.

1.2.6 Regional Product Centres – RPC

An RPC offers the local business unit (from now on BU) or distributor one or several of the following services: pipeline management including stock refill, complete knock-down (from now on CKD) or semi knock-down (from now on SKD) assembly, local adaptations (fit-for-use, from now on FFU), body building, pre delivery inspection (from now on PDI) and outbound transport (from RPC to agreed delivery point). (Scania, 2013c)

Presently, eight RPCs exist globally. They are situated in Belgium, Malaysia, Russia, South Africa, South Korea, Thailand, Taiwan and the United Arab Emirates. In May 2013, a new RPC in India was inaugurated. In Figure 3, the production units (from now on PRUs) and the RPCs are indicated. Note that there are other PRUs within the Scania organisation but these are not part of this study and are thus left without further notice.
CKD vehicles assembly is suitable for markets with high customs duties on completely built units (from now on CBU) and cheap labour. CKD basically means that components are produced at the PRU, packed in kits and sent to CKD assembly units (e.g. an RPC). CBUs, on the other hand, are vehicles that are already assembled at the PRUs and then delivered to the customer. (Balázs, 2013)

Figure 4 depicts a simplified flowchart of the current setup, from production at the PRUs to arrival at the end customer. P&L and Sales & Services (from now on S&S) are organisational notions, while PRUs and RPCs are physical locations. The RPCs serve the BUs/distributors with finished products. Main activities of the RPCs include logistics governance e.g. customs clearance, of deliveries from PRUs to RPCs, assembly of component kits at the RPCs, adaptations, body building, PDI and delivery to customer. (Balázs, 2013)

BUs/distributors on RPC markets sell both refill vehicles and non-refill vehicles. The first-named type refers to a limited number of standard models that are supposed to always be available in stock at the RPCs and therefore can be sold and delivered immediately, whilst the later type refers to vehicles that are customer specific and not kept in stock. The ordering of refill vehicles is triggered by monthly forecasts that the BUs/distributors provide the RPCs with. The RPCs send the orders to the order office, with respect to their stock and buffer levels. (Balázs, 2013)

1.3 PROBLEM BACKGROUND

1.3.1 The Origin of the RPCs
The first RPC within MDO was established in 2006. The setup before the creation of the RPCs is illustrated in Figure 5. As can be seen in the figure, the process is the same, but the owners of it are
not distributed as now. P&L only owned the first step in the process at that time and S&S the rest but now P&L owns step one to six and S&S step seven, as in Figure 4. (Balázs, 2013)

There were several underlying reasons why the RPCs were established. Scania wanted to increase its market shares in several markets lying far away from the PRUs in Europe and Brazil. In order to realise fast deliveries, local presence was seen as an essential step in order to come closer to the markets. It was also a question about core businesses. The S&S departments should focus on selling vehicles and taking market shares, not production and logistics that is P&L’s core business. Scania believed that with P&L carrying out the production and logistics part in the chain, lead times could be reduced, tied-up capital decreased, productivity increased, the understanding of the local market could be improved and thus more adapted products and services could be offered. In addition, the control of the pipeline could be improved. In order to create the RPCs, Scania took over productions from the S&S or private owners at markets where the volumes were relatively high and the political complications limited. Creating new PRUs that manufacture components in any of the countries lying far from the existing PRUs has not been an option since the investment required is very high and it is often legally complicated. (Balázs, 2013)

1.3.2 Current State
The total stock levels (buffer, stock and stock at the BU/distributor) have not decreased as expected, compared to the levels before the creation of the RPCs. Shortages rarely occur in comparison to excesses. Due to long lead times (often three to four months from order to delivery to stock) that are mainly caused by long transportation distances, the pipeline contains an important number of vehicles. The long lead times and the high stock levels contribute to an important amount of tied up capital. In addition, long lead times combined with insecure demand forecasts make accurate planning difficult. Today, the tools that are available are very rough and do not take that many factors into account. (Balázs, 2013)

1.3.3 Wanted State
From management’s point of view, a reduction of the high stock levels as well as lead times would be desirable due to the significant tied up capital that this generates. In a tough macro-economic climate where stagnation frequently has been the case during the past years, Scania needs to reduce costs and at the same time capture a maximum of selling opportunities. Therefore the RPCs must be able to provide the BUs/distributors with the vehicles they want and at the right time. (Balázs, 2013)

The current setup with RPCs, see Figure 4 above, requires that the BUs/distributors trust the RPCs. The BUs/distributors should get what they have forecasted and what, as a consequence of the forecast, has been ordered. This is why the need of a transparent pipeline becomes important. The RPCs must be able to show that they can manage to deliver the required volumes and it is important for the BUs/distributors that they can see what is in the pipeline in order to give appropriate answers to customer requests. (Balázs, 2013)
The consequences of forecasted volumes, order behaviour and lead time variations need to be visualised so that more optimised decisions regarding the pipeline can be made in the future in order to minimise lead times, stock levels and buffer levels and maximise service levels. This can be realised by means of a simulation model. (Balázs, 2013)

1.4 PURPOSE
The purpose of the study is to create a simulation model, based upon a process mapping, that visualises future volume levels in the pipeline due to different demand and ordering scenarios.

The short term target, which is also the target of this study, is to increase the RPCs’ understanding for how different demand and ordering scenarios influence the future volume levels in the pipeline.

The long term target is to reduce tied up capital by adjusting buffer levels and lead times, while still ensuring a certain service level. The model should contribute to more accurate decision making with respect to the previous mentioned aspects.

1.4.1 Purpose Specification
Process mapping is to investigate the structure and elements included in or connected to the pipeline such as information and material flows, main activities and limitations.

Create in this context encompasses several steps. Primarily, it is to investigate and determine which parameters and variables that should be included in the model, which requires general process mapping. Secondly, it is to examine how the parameters and variables are related to each other. Thirdly, the simulation model has to be made. Finally, the model needs to be tested and verified.

The simulation model is a simple mathematical representation of the pipeline. It does not give an optimal solution, but a particular result given specific input values. For further explanation, see section 2.5 Modelling and Simulation.

To visualise is to render less comprehensible and to some extent abstract data more clear, understandable and communication friendly.

Volume levels are the number of vehicles at different stages in the pipeline.

The pipeline is the flow that starts when a forecast is sent to an RPC from a BU/distributor and that ends when the BU/distributor has been invoiced for the vehicles, which normally coincides with when the vehicles leave the finished goods inventory (from now on FGI) at the RPC.

A demand scenario is a given set of forecasted demand volumes for different periods in time while an ordering scenario is the planned order volume during the corresponding periods.

1.5 DIRECTIVES AND DELIMITATIONS

1.5.1 Directives
In brief, the simulation model should represent the pipeline and its inputs and outputs that are necessary in order to make an accurate volume simulation. The process starts when a forecast, sent from the BU/distributor, arrives at the RPC and ends when S&S is invoiced for the vehicle, which normally coincides with when the vehicle leaves the FGI at the RPC (the yard). For more information about the studied system, please refer to section 3.1 The Systems Approach.
1 Introduction

The below mentioned directives have been given by Scania.

- The RPC in the United Arab Emirates is excluded from the study, since the process regarding this RPC differs much from the other RPCs. Here, stock levels are set once every quarter, usual forecasts are made, but are not used for order planning. The pipeline management is thus very specific in this case.
- The RPC in Belgium will not be included in the study since it is currently subject to change and the future working process is uncertain.
- The RPC in India is also excluded from the study, due to recent establishment and on-going ramp up.
- The simulation model should be created in Microsoft Excel but the use of Visual Basic should be avoided to an as large extent as possible in order to facilitate for future developers.
- The simulation model should be as generic as possible in order to facilitate the introduction of possible future RPCs.
- The simulation model should not include the BUs/distributors, e.g. their stock levels, since the forecasts made by the BUs/distributors should take their own stocks into account. In addition, S&S and P&L are different profit centres.
- The main thing to visualise in the simulation model is the stock levels of the refill models. However, non-refill models affect the capacity available at the different stages in the pipeline and therefore need to be taken into consideration to some extent.
- The simulation model should be as simple as possible, still rendering significant results. It should also be user friendly and visualise the results in a clear way, e.g. graphically.
- Forecasts that will serve as input data to the model are assumed to be accurate.
- Forecasts should be updated at least every month; however a plan for wanted deliveries to BUs/distributors should be updated once a week.
- Ordering should be made once a week.
- The simulation model should be based upon a granularity corresponding to a week, i.e. the number of vehicles in each week of the pipeline should be visible.

1.5.2 Delimitations

The below stated delimitations have been set during the study.

- One RPC cannot simulate that goods from different PRUs arrive, i.e. it is not possible to simulate different lead times for different goods. This delimitation is further developed in section 6.1.3 Flexibility.
- The simulation model will not take into account that all goods actually are moving forward in the pipeline as batches and that it is always assembled at the RPCs in batch sequences. This delimitation is necessary in order to not make the simulation model too heavy, since taking batches into account would imply earmarking of each batch. This delimitation is further developed in section 6.3.1 Relationships between the Variables and Parameters.

1.6 Target Groups

This study has three main outputs; firstly, an academic report including scope, underlying theory, method, empirics, analysis, results and a final discussion, secondly, a process map and thirdly a simulation model. The academic report can be of interest for students and other academia, employees at Scania and other persons interested in the area. The process map and the simulation
model are dedicated to Scania. The owner of the simulation model is MDO, the users are the RPCs and one of the output receivers will maybe be the BUs/distributors. As an owner, MDO will be maintaining the simulation model and implementing the use of it.

1.7 Structure of the Report

In Table 1 below, the structure of the report is presented. Each main chapter’s content is explained briefly and hopefully this will help the readers of the report to quickly identify where they can read about the areas that they are interested in.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>In this chapter a brief presentation of Scania is given and then an explanation to the background of the problem, that is source to the study, is presented. As a result of the problem background, a purpose for this study is elaborated and specified. In order to clarify what is included in the study and what is not, received directives and chosen delimitations are presented. The final section of the chapter points out the target groups of the study’s output and shows the structure of the report.</td>
</tr>
<tr>
<td>2. Theoretical Framework</td>
<td>In this chapter several different theories and definitions from multiple sources are presented. The aim is to give a broad, but still relevant, theoretical foundation for the task formulation, and further on, the rest of the study. Some of the theories and definitions converge, others diverge. Own judgments and opinions are written in a clear way when those have been regarded as necessary. Selections of which theories and definitions to use will be made in the subsequent chapters. Please note that all definitions and theories are not used later in the study but are considered essential in order to understand the overall problem.</td>
</tr>
<tr>
<td>3. Task Formulation</td>
<td>In this chapter a brief introduction to the systems approach, and how this can be applied in the study, is given. The analysis model is a combination of elements from mathematical modelling and a logistics case analysis framework. Finally, all parts of the analysis model are broken down further into specific questions that are considered key in order to meet the purpose.</td>
</tr>
<tr>
<td>4. Methodology</td>
<td>In this chapter an introduction to the methodology approach is given at first. Second, relevant methodology theories are presented. These theories are alternated with how this study was conducted including how answers to the questions from the task formulation have been found. Finally, the credibility of the study is evaluated. Here, the authors highlight advantages and drawbacks of the study in a constructive way. The aim of this part is to give the reader a comprehensive view of what has influenced the study and what could have been made differently.</td>
</tr>
<tr>
<td>5. Process Mapping</td>
<td>In this chapter the findings made during both the high level and detailed level process mappings that have been conducted are presented. Pure empirics are alternated with analysis in order to go from a wide perspective including all flows, then determine which flows that can be considered representative and finally generalise and apply the findings from the representative flows on the remaining flows. At the end of the chapter, verifications are presented that confirm the findings.</td>
</tr>
</tbody>
</table>
### 6. Prerequisites to Simulation Model Creation

In this chapter important input to the model creation phase is presented. Several aspects that are important to be aware of and areas that the creators should have knowledge in are explored. For example, discoveries made during the mapping process are broken down into parameters and variables, activities and stocking points are aggregated and simplifications are made. In addition to this, many user-related issues are treated and model requirements set, everything in order to create a clear recipe of what is to be created and minimise the development time for the simulation model.

### 7. Development and Validation of the Simulation Model

In this chapter the findings regarding user-friendliness and robustness are first presented. Then, the creation process of the simulation model is described and finally the testing of the simulation model in order to ensure its accuracy and validity is explained.

### 8. Justification and Delivery

In this chapter a description of the simulation model is given and the advantages and the drawbacks of the simulation model are explored and explained. In order to strengthen the reasoning behind the explanations, examples are provided.

### 9. Conclusions and Discussion

In this chapter the fulfilment of the purpose is evaluated. Also, general reflections upon the study are presented. The studied system and its different parts are put into a wider picture permitting a more extended analysis. The use of the study’s outputs is analysed and possible generalisations and potential for further development are explored. General recommendations regarding the use of the simulation model are given and in addition, suggestions for further research are presented.

### 10. Bibliography

In this chapter the written, electronic and oral sources that have been used during the study are presented.
In this chapter several different theories and definitions from multiple sources are presented. The aim is to give a broad, but still relevant, theoretical foundation for the task formulation, and further on, the rest of the study. Some of the theories and definitions converge, others diverge. Own judgments and opinions are written in a clear way when those have been regarded as necessary. Selections of which theories and definitions to use will be made in the subsequent chapters. Please note that all definitions and theories are not used later in the study but are considered essential in order to understand the overall problem.
2 Theoretical Framework

2.1 LOGISTICS

2.1.1 Definition of Logistics
There are several definitions of logistics within industries and businesses around the world. Lumsden (2012) states that the classic logistics definition, which is based on research and education, is the one introduced by Shapiro and Heskett in 1985:

“Logistics is defined as those activities that relate to receiving the right product or service in the right quantity, in the right quality, in the right place, at the right time, delivering to the right customer, and doing this at the right cost (The seven R’s).” (Translated from Lumsden, 2012, pp.22-23, originally from Shapiro & Heskett, 1985)

Another definition was introduced by The Council of Supply Chain Management Professionals, which is considered as the world’s leading source for the supply chain profession. This organisation defines logistics as follows:

“Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers’ requirements.” (Council of Supply Chain Management Professionals, 2013)

Jonsson and Mattsson (2011) consider the material flow being the object of the logistics concept. These authors specify that logistics is all about effective material flows but also that it is vital to understand the information flow within the organisation to create these material flows. With this approach, Jonsson and Mattsson (2011) define logistics as:

“[…] the planning, organisation, and control of all activities in the material flow, from raw material until final consumption and reverse flows of the manufactured product, with the aim of satisfying customers’ and other interest parties’ needs and wishes i.e., to provide a good customer service, low cost, low tied-up capital and small environmental consequences.” (Translated from Jonsson & Mattsson, 2011, p.20)

Furthermore, Jonsson and Mattsson (2011), describe that logistics can be an object of study both in a part of a chain or an organisation or in an organisation as a whole. Lumsden (2012) agrees with this but presents a paradox stating that it is hard to see the benefit of every single part when studying the whole organisation but that it is difficult to realise how everything is connected when studying every component separately. According to Lumsden (2012) it is important to start with simple relations and rough theoretical guidelines, which automatically lead to a comprehensive view.

2.1.2 Delivery Service and Logistics Costs
According to Oskarsson et al. (2006), the goal of logistics is that all customers should get the products they want, in the right place and at the right time, with acceptable costs for the whole value chain. Oskarsson et al. (2006) claim that two things are important to achieve within logistics: high delivery service and low costs. Reichhart et al. (2008) apply this logistics goal at the complete supply chain and add that a lot of trade-offs need to be taken into account. Lumsden (2012) presents a quandary
and states that an effort that might decrease the logistics costs might also decrease the delivery service and vice versa. Due to this it is important to consider the entirety when making logistics decisions.

Delivery service can be divided into six elements: lead time, delivery accuracy, delivery reliability, information, flexibility or customer adaption and fill rate. These elements give a comprehensive representation of the delivery precision. (Oskarsson et al., 2006; Lumsden, 2012)

The lead time is according to Oskarsson et al. (2006) the time between when the order is placed and the delivery of the product or the service. This will be further developed later in this chapter.

The delivery accuracy is the reliability in lead time while the delivery reliability is the reliability in quantity and quality. Information exchange is becoming more important when the delivery precision demands are increasing. The selling party needs to get customer demands as early as possible to have a possibility to plan the production and the buying party would like to be informed about e.g. which delivery precision they can expect. Customer adaption includes special services that the customer might be interested in, such as special deliveries or express transports. The fill rate is usually used when producing to stock and is then a measure of how many orders or order rows that can be delivered when the customer wants. When producing to order this measure is irrelevant. (Oskarsson et al., 2006)

To cover all the logistics costs and to derive where they come from, it can be of interest to classify them. One usual way is to divide the logistics costs into five different categories: inventory carrying, inventory holding, transportation, administration and miscellaneous. (Oskarsson et al., 2006)

Oskarsson et al. (2006) describe the inventory carrying costs as the costs the products in an inventory generate, i.e. cost of tied up capital and risk costs. Furthermore, the same authors define the inventory holding costs as the costs that are generated when holding the actual inventory, e.g. building rental costs and staff costs. Olhager (2000) on the other hand, does not split these costs and includes the tied up capital costs in the holding inventory costs. The costs related to inventory will be further explored later in this chapter.

The transportation costs include the costs for all transports and administration of transportation in the company, except transportation costs within the company buildings (since these are inventory holding costs). Administrative costs occur during the logistics chain in a company, e.g. administrative costs are costs for order handling and costs for invoicing. Expenses that are included in miscellaneous are e.g. expenses for packing and labelling. (Oskarsson et al., 2006)

In Figure 6, the different logistics costs and the delivery service elements are visualised.
Stock and Lambert (2001) present another total cost concept, which is depicted in Figure 7. In the figure, it is shown how five major logistics costs support the customer service. The authors argue that it is very difficult to measure the costs of customer service and therefore the most appropriate approach is to fix a customer service level and then try to provide this service level while minimising the total expenditures. (Stock & Lambert, 2001)

A strong characteristic of this study is long lead times; therefore the lead time notion is further developed below. Another main underlying problem in this study is high inventory levels and thus an important amount of tied up capital. Therefore a special section about inventories is also presented below.

**Lead Time**

Lead time is, as mentioned above, one of the customer service elements. The notion is defined as the time it takes from when an order has been placed to when the product or service has been delivered. Within one lead time there can be several shorter lead times. For example, if a manufacturer needs to order a transport in order to deliver a product, this is only one part of the lead time perceived by the customer. However, this is in itself a lead time since it means that an order has been placed and a service delivered. Short lead times are in some cases a very important aspect for the customer. (Oskarsson et al., 2006)
The definition of lead time varies depending on the context in which it is used. However, in general it is the time that elapses from when a need of one or several activities arises until it is known that these are accomplished. Lead time for product development, lead time for delivery with respect to a customer’s point of view and production lead time according to a manufacturer’s point of view are three main variants of the lead time definition. (Olhager, 2000)

Another, and to some extent narrower, definition is stated by Anupindi et al. (2012, p.138) who define lead time as “the time lag between the arrival of the replenishment and the time the order was placed”. The lead time definition in this case is strongly related to inventory analysis and more specifically ordering decisions.

Lumsden (2006) also defines lead time as the time from order to delivery and in addition to this the lead time can be seen as the customer’s total time of waiting. The author claims that lead time consists of several parts including various activities. These parts are the following; order, planning, engineering, processing and distribution. Lead time is something that is associated to physical flows and that describes the time from material supply until delivery. In recent years, lead time has gained importance since it has become a key source of income if it can be kept short. Short lead time contributes to a high service level to the customer and a reduced amount of tied up capital. Moreover, if a company can manufacture and distribute products during the time a customer can accept to wait, the need of a finished goods inventory is reduced. (Lumsden, 2006)

Christopher (2011) mentions two perspectives of lead time. The first perspective is the customer perspective, which is the order-to-delivery cycle illustrated in Figure 9. Each step in the figure corresponds to a certain time which often varies due to e.g. capacity limitations. This implies that the final lead time will be situated within a time range that varies depending on the time uncertainty in every step. (Christopher, 2011)

The second perspective is the supplier’s perspective, which is the cash-to-cash cycle. This cycle is the time it takes to convert an order into cash and the time that working capital need to be financed. (Christopher, 2011)
2 Theoretical Framework

Short lead times often give important competitive advantages. If the pipeline from the purchase of material to end customer is long, the demand system will be less responsive. In addition to this, a long pipeline makes it difficult to connect the manufacturing and procurement decisions to the requirements of the market in a visible way, something that often results in high inventory levels. (Christopher, 2011)

Inventories

Inventory Management
Generally, inventories cost a lot and in order to get better cash flow as well as return on investment it is of importance for companies to have good inventory management. One of the main tasks for inventory managers is to decide when to order and at what quantity. The way of doing this reordering depends on whether the situation can be regarded as certain or uncertain, several methods exist. (Stock & Lambert, 2001)

Stock and Lambert (2001) claim that the objectives of inventory management are three:

1. Increase corporate profitability: This can be realised either by lowering inventory cost or increase sales. Higher service level often implies less lost sales but the hold of inventory is costly.
2. Predict the impact of corporate policies on inventory levels: This means e.g. being able to predict changes in inventory quantities if the corporate hurdle rate will change.
3. Minimise the total cost of logistics activities: This means that management has to establish the inventory level needed for achieving the least total logistics cost while still being able to satisfy the customer service objectives.

Why Inventories are Hold
According to Stock and Lambert (2001) there are five reasons why a company should hold inventories. The first reason is that it permits the company to reach economies of scale e.g. by transporting larger volumes at the same time or being able to buy larger volumes and thus getting more attractive prices from suppliers. The second reason is that keeping inventories can ensure that supply and demand is balanced. For example, the demand may vary with seasons and producing exactly when the peaks appear might be expensive. The third reason is that inventories may enable the manufacturer to specialise, e.g. it can be beneficial to conduct longer production runs instead of short ones. The fourth motive for inventory holding is that it can protect the company from uncertainties in order cycle or demand. Three main inventory types held due to this motive are raw materials inventory (e.g. when prices are expected to rise dramatically), work-in-progress inventory (e.g. due to bottlenecks) and FGI (e.g. in order to avoid stock outs). The last reason to why inventory might be held is that is can be a buffer between critical points in the supply chain. Several interfaces that might be critical within the supply chain exist such as Supplier-Procurement, Production-Marketing, Marketing-Distribution and Intermediary-Consumer. (Stock & Lambert, 2001)

According to Lumsden (2012) there are several motives for holding inventories. Costs as well as customer relationships are both important and holding inventories does not necessary have to be a bad thing as long as the sizes of the inventories are well deliberated according to certain criteria. In the short run, optimisation of the inventories can be made, but in the long run the company should strive for better conditions so that inventory holding can be reduced. Uncertainties have to be
eliminated so that safety stocks can decrease. Holding inventories is not a purpose of its own. The general rule is that inventory levels should always be kept as low as possible. (Lumsden, 2012)

Christopher (2011) describes how inventories sometimes can hide underlying problems such as bottlenecks, quality problems, inaccurate forecasts and industrial relations problems to mention a few. The Japanese Kanban idea is related to this. A system that is driven by demand at the lowest point in the chain, a so called “pull” system, is a Kanban system. The Kanban system ensures that only the quantity needed and at the time it is needed is provided. If the quantity can be reduced, i.e. the amount that the supplying station is asked for, a possible bottleneck will start to be visible and the work with removing it in a cost effective way can start. (Christopher, 2011)

Categories of Inventories
Stock and Lambert (2001) claim that the six below mentioned types of inventory categories exist:

1. Cycle stock: “Cycle stock is inventory that results from the replenishment process and is required in order to meet demand under conditions of certainty – that is, when the firm can predict demand and replenishment times (lead times) perfectly.”
2. In-transit inventories: “In-transit inventories are items that are en route from one location to another.”
3. Safety or buffer stock: “Safety or buffer stock is held in excess of cycle stock because of uncertainty in demand or lead time.”
4. Speculative stock: “Speculative stock is inventory held for reasons other than satisfying current demand.”
5. Seasonal stock: “Seasonal stock is a form of speculative stock that involves the accumulation of inventory before a season begins in order to maintain a stable labor force and stable production runs or, in the case of agricultural products, inventory accumulated as the result of a growing season that limits availability throughout the year.”
6. Dead stock: “Dead stock is the set of items for which no demand has been registered for some specified period of time.” (Stock & Lambert, 2001, pp.232-235)

Lumsden (2012) argues that inventories can be categorised into five main types according to the reason for why they exist:

1. Cycle stock: Cycle stocks depend on a trade-off between ordering cost (procurement or setup costs) and the cost of stock keeping.
2. Safety stock: Safety stocks are held in order to being able to deliver despite surrounding uncertainties. It depends on the lead time length, the demand during the lead time and the balance in the inventory registers.
3. Seasonal stocks or level stocks: Seasonal stocks or level stocks are often a result of a company wanting to keep a high and balanced capacity use even though the demand might vary seasonally. When the setup costs or costs of change in capacity are high it can be beneficial to hold inventory as a buffer between production and sales.
4. Process inventory: The layout of a production or transportation system may imply that some inventory holding cannot be avoided. An example of process inventory is products that are being treated in the production or transported.
5. Coordination stock: Coordination advantages can occur e.g. when material is going to use the same tool, which makes stock less expensive than the order cost. Another example is when
2 Theoretical Framework

an assembly is to be made and all the parts are not available at the same moment. (Lumsden, 2012)

Inventory Carrying Costs
Stock and Lambert (2001) state that:

“Inventory carrying costs, the costs associated with the quantity of inventory stored, include a number of different cost components and generally represent one of the highest costs of logistics. The magnitude of these costs and the fact that inventory levels are influenced by the configuration of the logistics system demonstrate the need for an accurate assessment of inventory carrying costs, if the appropriate trade-offs are to be made within the supply chain.” (Stock & Lambert, 2001, pp.193-194)

According to these authors, inventory carrying costs incorporate costs that vary with the quantity of inventory and that can be classified into capital costs, inventory service costs, storage space costs or inventory risk.

When a company holds inventory, it ties up capital that could be used in another way, e.g. as an investment in something else. Therefore, the rate of return that could be obtained by using the money differently (also known as the company’s opportunity cost of capital), should be employed when computing the capital costs. (Stock & Lambert, 2001)

2.1.3 The Logistics Pipe
Oskarsson et al. (2006) describe the logistics flow in a company as a pipe where the length of the pipe is a product’s cycle time. In Figure 10, the pipe is expressed in three parts. Note that there are inventories in between the three parts but those are not depicted in the figure.

To create high delivery service to low costs, the capacity of the pipe should match the demand of the market. This means that the width of the pipe might expand if the market demand increases. Making the pipe shorter normally leads to reduced lead times and tied up capital. Also, a shorter pipe decreases the need of buffer stocks. (Oskarsson et al., 2006)

To slim the logistics pipe, Oskarsson et al. (2006) state that the capacities in the different parts of the pipe should be as equal as possible. With different capacity in different parts of the pipe unnecessary stocks might occur, which influence the tied up capital negatively. Oskarsson et al. (2006) describe the part in the pipe with the lowest capacity as a bottleneck that limits the throughput in the pipe. Due to Anupindi et al. (2012) the effective capacity of a process can be defined as the effective capacity of the bottleneck. For further information about bottlenecks, see section 2.2.4 Bottlenecks. Olhager (2000) points out that the unnecessary stocks named above can be considered as buffer
stocks and that they in some cases are positive, e.g. when they occur in front of a bottleneck. Due to Olhager (2000) the reason to this is that if there is any temporary disturbance in the pipe upstream the bottleneck, the output of the bottleneck activity will not be influenced.

The logistics pipe is different in different companies and it varies depending on e.g. market situation and industry. Normally, there is some kind of order to delivery process between every part of the pipe, i.e. that every division in the company needs to order more material or products and the division upstream needs to deliver it. Without these processes, the material or products should not move through the pipe. (Oskarsson et al., 2006)

Tarkowski et al. (1995) point out that there are information flows parallel with the product flows in the logistics pipeline. Since the product flows tend to contain several smaller product flows, all these information flows depend on each other. According to Tarkowski et al. (1995), this information flow complexity needs to be taken into consideration when creating a logistics pipeline.

A supply channel is according to Ross (2004) defined as a pipeline through which products flow from the supply source to the customer. Ross (2004) describes that very few products are sold directly from the producer to the end customer. Normally, there are one or several steps in between, e.g. wholesalers, retailers and company-owned distribution centres. In Figure 11, three different supply channel structures can be viewed. Ross (2004) means that the level of integration in a supply channel largely depends on the characteristics of the market and the product.

Ross (2004) explains that supply channels also could be defined by the functions executed in the distribution pipeline rather than the organisational functions. According to Ross (2004), it is however almost impossible to separate the departments from the actual activities but it is still much more useful since it focuses on the mechanics of the channel.

2.1.4 Logistics Pipeline Management
Christopher (2011) argues that pipeline management is key in order to get control over logistics lead times. The author states that:

“Pipeline management is the process whereby manufacturing and procurement lead times are linked to the needs of the marketplace. At the same time, pipeline management seeks to meet the competitive challenge
Pipeline management has four main aims: cost reduction, quality increase, flexibility increase and response time reduction. An important part of attaining these goals is to identify value-adding time and non-value-adding time. The first one requires flowcharting of the supply chain process and then determination of which parts that are value-adding or not. Value-adding time is time during which value is created for the customer and the customer is willing to pay for it. It is essential when working with logistics processes and improvement of these to be aware of the difference between value-adding time and non-value-adding time. When the determination is done, it can be visualised by e.g. a graph with value added on the vertical axis and cost added on the horizontal axis (Figure 12) or percentage of total cost added by logistics processes through time. It is important to visualise the value added over time, since it gets more expensive to hold inventory in later part of the pipeline if most of the value was added in the beginning. (Christopher, 2011)

One important part of pipeline management is strategic lead-time management. Strategic lead-time management is concerned with compression of the chain. This is depicted in Figure 12 below. As can be seen, non-value-adding time is focused on and reduced by improvements. (Christopher, 2011)

A way of measuring the efficiency of a supply chain is to compute the throughput efficiency.

\[
\text{Throughput efficiency} = \frac{\text{Value added time}}{\text{End-to-end pipeline time}} \times 100
\]

If the throughput efficiency is low, most of the time spent in the supply chain is non-value-adding time. (Christopher, 2011)

Pipeline management is also responsible for trying to eliminate blockages and fractures which cause increased response times and inventory levels. Blockages and fractures can occur due to several
reasons, e.g. bottlenecks, extended set-up or inadequate pipeline visibility. Christopher (2011) also argues that if logistics process improvement is going to be realised, it is necessary to put the whole chain in the centre of attention. One important thing to analyse more in deep, is the interfaces between the components in the logistics process, since this allows to re-engineer the process. (Christopher, 2011)

2.1.5 Transportation

According to Oskarsson et al. (2006), transportation is constantly present during the logistics processes within a company. The same authors exemplify that transportations are used internally between inventories within a company or externally between different urban areas or companies.

Oskarsson et al. (2006) state that many companies decrease the goods volumes and increase the transportation frequency to slim their inventory levels. Furthermore, the transportation buyers demand short lead times, high delivery service and low costs. These requirements have, together with high flexibility demands, strongly influenced the transportation system and its structure. (Oskarsson et al., 2006)

The logistics system is a combination of the transportation object, the infrastructure and the means of transportation. An information system holds the elements together. In Figure 13, the transportation is considered to be the link between the means of transportation and the transportation object. The traffic is a link between the means of transportation and the infrastructure whilst the distribution links the transportation object and the infrastructure. (Tarkowski et al., 1995)

![Figure 13. Elements and Processes in the Logistics System (Source: Tarkowski et al., 1995)](image)

Tarkowski et al. (1995) describe traffic as the physical movement that is required to move the transportation objects. The means of transportation are needed to move the transportation object in the logistics network. The logistics network is based in the infrastructure. The transportation is defined as a change of location while distribution has the purpose to make the relocation of the transportation objects within the network feasible. (Tarkowski et al., 1995)

Lumsden (2006) presents several means of transportation. One of these is according to Lumsden (2006) sea transport, which due to the size of the ships is relatively cheap when transporting goods. Lumsden (2006) points out that it is important not only to decrease the transportation time but also to look over the time in every stage in the transportation system.
2 Theoretical Framework

Tarkowski et al. (1995) point out that a transportation service is easy to copy, why it is hard to use other parameters then cost as competitive advantage. The same authors continue that the transporters role basically only is to deliver goods from one point to another. However, Tarkowski et al. (1995) point out that the delivery service is important and a useful way to differentiate from competitors.

2.2 PRODUCTION

2.2.1 Definition of Production

A general and traditional definition of production is given by Olhager (2000). The author claims that the production function is a transformation process. Resources are transformed into products or services. Figure 14 below depicts the transformation process. (Olhager, 2000)

![Figure 14. The Production Function as a Transformation Process (Source: Olhager, 2000)](image)

2.2.2 Production Triggers

A common notion within the production function is the order penetration point (from now on OPP). The OPP corresponds to the position in the value chain where a specific customer order is linked to a specific article. Several setups are possible depending on where in the value chain the OPP lies, as can be seen in Figure 15. (Olhager, 2000)

![Figure 15. OPP at Different Places in the Value Chain (Source: Olhager, 2000)](image)

Make-to-stock means that the OPP lies in the finished goods inventory. This type of production is trigged by expected demand e.g. forecasts. Make-to-stock (from now on MTS) is common for high volume standard products. An OPP placed late in the value chain reduces the customer lead time; however the need of forecasting increases. (Olhager, 2000)
Having the OPP in the distribution part of the value chain has two pros; long and economic production series are possible and the delivery time is short. The cons are that the amount of tied up capital is higher and the possibility to adapt the product to the customer decreases. Contrary, having the OPP in the production part of the value chain has two pros; greater possibility to adapt the product according to the customers’ requirements and decreased amount of tied up capital. The cons are that the delivery time is longer and the production and procurement costs often are higher. (Oskarsson et al., 2006)

2.2.3 Production Planning and Control
Planning and controlling of production on tactical and operational level is often called manufacturing planning and control (MPC). The company’s business plan gives the main frames for what will be produced in the short run as well as the long run. This is depicted in Figure 16. (Olhager, 2000)

![Figure 16. General System for Planning and Control of Material and Capacity (Source: Olhager, 2000)](image)

Major objectives for the production planning and control are high customer service by short and certain delivery cycles, low production costs by high and balanced resource use and low costs for tied up capital in raw material inventory, work-in progress and finished goods inventory by a short throughput time. Achieving all the objectives simultaneously is difficult and it is often necessary to prioritise. Four main things have to be decided regarding production planning. First, what should be made, second, which quantity that should be produced, third, when to produce and fourth, which resources to use. (Olhager, 2000)

2.2.4 Bottlenecks
Logistics processes are interlinked activities within a network. In order to optimise the whole system, it is useful to take a closer look on the total throughput time. Focusing on the activities in the process one at a time will lead to sub-optimisation. Optimised production technology, also known as the theory of constraints, is a theory saying that every single activity in the process can be classified as a bottleneck or a non-bottleneck. The slowest activity in a chain is a bottleneck; it can e.g. be a machine or an information flow. The activities categorised as bottlenecks determine the throughput time of the system. Therefore, if wanting to reduce the throughput time of the system, it is essential to work with the bottlenecks and try to add capacity where it is needed. Adding capacity to non-bottleneck activities should be avoided, since the only thing this result in is that it will create even
more inventory at the next bottleneck activity. Within logistics systems, the aim is to reduce the throughput time as well as the inventory. Managing bottlenecks appropriately is key in order to realise this. Batches should be larger in bottleneck activities in order to avoid the number of setups in these activities. The contrary applies for non-bottleneck activities. (Christopher, 2011)

Lumsden (2012) argues that many companies find it difficult to dimension and organise its resources and the reason for this is that there almost always are constraints affecting the system’s output. A resource limiting the system will contribute to a growing work-in-progress in the process since the company is striving for maximal use of each resource. The result of this is growing lead times, higher costs, important amounts of tied up capital and a decrease in the company’s capability of being able to respond to the demand. (Lumsden, 2012)

Every system has bottlenecks, i.e. limitations to the capacity, and these lead to an unbalanced flow in the system. Therefore, the bottlenecks have to be identified and used to the largest possible extent. There are three main rules when it comes to using a bottleneck as much as possible. Firstly, if an hour is lost in a bottleneck, an hour is also lost in the whole process. Secondly, an hour that is worked in before the bottleneck does not matter since the system output will not increase anyway. Finally, the optimal thing to do is to provide bottlenecks with material at the same pace the bottleneck can take care of it. (Lumsden, 2012)

2.3 SUPPLY CHAIN MANAGEMENT

2.3.1 Definition of Supply Chain Management
The Council of Supply Chain Management defines supply chain management as follows:

“Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.” (Council of Supply Chain Management Professionals, 2013)

Another supply chain management definition was elaborated by The Global Supply Chain Forum during the 1990s. (Lambert et al., 1998)

“Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders.” (Lambert et al., 1998, p.1)

2.3.2 The Supply Chain Elements
A supply chain is a combination of players that are dependent of each other. These players can be part of e.g. a company, a corporate group or different companies. Internally in a company, a supply chain is built up by different functions that perform activities. When expanding this view and talking about supply chains with external actors, a comprehensive view can be depicted. Normally when talking about supply chains, this expanded supply chain is intended. (Mattsson, 2002)
In Figure 17, the supply chain is presented. In this case, the supplier’s suppliers and the customer’s customers are not comprised in the supply chain. According to Mattsson (2002), these should be included if the supply chain is expanded.

![Expanded Supply Chain](Source: Mattsson, 2002)

Global supply chains are some of the most central processes in businesses since they include many organisations and stretch from basic resources to final markets. A supply chain is a process that begins with a customer’s demand, which shape the supply chain and its activities. In order to be able to manage the supply chain in a good way it is essential to understand its structure and three steps have to be followed (Skjøtt-Larsen et al., 2007):

1. Develop a framework for analysis;
2. Distinguish the nature of the supply chain;
3. Identify the involved processes.

The involved processes shape, together with the organisational units and the activities, the supply chain. The organisations are responsible for the performance, while the processes manage and link the activities. The organisations are needed to manage and supply resources but the activities are the ones that operate the supply chain. For example, an order process includes different order activities performed by both suppliers and customers (cross organisational) and therefore need predefined actions and synchronisation, managed by these organisations. (Skjøtt-Larsen et al., 2007)

Cooper et al. (1997) explain that the supply chain management framework contains three elements: business processes, management components and the structure of a supply chain. The business processes are the activities that generate an output to the customer. These processes are built-up by the management components and the structure of the supply chain is the configuration of the organisations and functions within the chain. In Figure 18 the supply chain management framework is visualised. (Cooper et al., 1997)
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Lambert et al. (1998) state that implementation of supply chain management engages identifying the supply chain members and linking these together.

Cooper et al. (1997) present eight general business processes that were identified by the International Centre for Competitive Excellence. These processes are: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement, product development and commercialisation. When these business processes link companies, they become supply chain business processes (Lambert et al., 1998). In Figure 19 the business processes across the supply chain are presented.

Figure 19 show how the processes stretch from the suppliers to the end customers through the manufacturers. In the manufacturing organisation there are several functions, e.g. logistics,
production and purchasing. Furthermore, the information flow is present in every organisation and function. The supply chain processes are the following:

1. Customer Relationship Management: “The customer relationship management process provides the structure for how the relationship with customer is developed and maintained, including the Product/Service Agreements (from now on PSAs) between the firm and its customers.”

2. Customer Service Management: “The customer service management - provides the firm’s face to the customer, including management of the PSAs, and provides single a single source of customer information.”

3. Demand Management: “Demand Management – provides the structure for balancing the customers’ requirements with supply chain capabilities.”

4. Order Fulfillment: “Order Fulfillment – includes all activities necessary to define customer requirements, design the logistics network, and fill customer orders.”

5. Manufacturing Flow Management: “Manufacturing Flow Management – includes all activities necessary to move products through the plants and to obtain, implement and manage manufacturing flexibility in the supply chain.”

6. Supplier Relationship Management: “Supplier relationship management provides the structure for how relationships with suppliers are developed and maintained, including the PSAs between the firm and its suppliers.”

7. Product Development and Commercialisation: “Product Development and Commercialization – provides the structure for developing and bringing to market new products jointly with customers and suppliers.”

8. Returns Management: “Returns Management – includes all activities related to returns, reverse logistics, gatekeeping, and avoidance.” (Croxton, 2003, p.20)

Since the process demand management is a central part of the study, it is explained more in deep below. Order fulfilment is also considered to be of importance, but not key, to this study and the process is therefore further developed in Appendix II. Supply Chain Processes.

**Demand Management**

According to Christopher (2011), demand management is:

“[…] the various tools and procedures that enable a more effective balancing of supply and demand to be achieved through a deeper understanding of the causes of demand volatility” while demand planning “is the translation of our understanding of what the real requirement of the market is into a fulfillment programme, i.e. making sure that products can be made available at the right time and place.” (Christopher, 2011, p.89)

The two terms together are entitled sales and operations planning (from now on S&OP). This is described as a six-step process, and the idea of the concept is depicted in Figure 20. (Christopher, 2011)
Croxton et al. (2002) describe the demand management process in deep. The demand management process is one out of several supply chain management processes and that it “is concerned with balancing the customers’ requirements with the capabilities of the supply chain” (Croxton et al., 2002, p.51). The demand management process comprises e.g. to forecast, to synchronise supply and demand, to increase flexibility, and to reduce variability. However, in some industries, it is more suitable to aim for accurate forecasts than increasing flexibility. (Croxton et al., 2002)

For even deeper information about the demand management process, please refer to Appendix II. Supply Chain Processes.

**Information in the Supply Chain**

Managing the supply chain includes, except managing the goods flow, managing information that is vital for planning and control. The flow of information can bring transparency into the complete supply chain, which is considered very important when dealing with the complex situations that might occur in a chain with different organisations. (Skjøtt-Larsen et al., 2007)

The type of information and with which frequency it is passed along the supply chain strongly affects the efficiency of the supply chain. Also, information is normally the first thing that is shared in the chain when companies are working towards creating a supply chain organisation. (Cooper et al., 1997)

In Figure 21, the power of visibility is shown. In the upper picture, the organisations do not have any information beyond the boundaries in the supply chain. In the second picture every part of the entire supply chain has access to the real demand information simultaneously and therefore has the possibility to react with minimal delay. (Skjøtt-Larsen et al., 2007)
Mentzer (2004) explains that having the ability to make strategic decisions in a supply chain is key. These decisions get more and more accurate as the decision maker get better and better information. Mentzer (2004) continues that information is playing a key role in today’s businesses since the market is getting more competitive as the environment get more uncertain and dynamic. Mattsson (2002) proposes that the quality of information can be divided into three parts: the correctness of the information, the completeness of the information and the timing of the information.

To be correct, the information needs to contain the message it was intended to deliver. Also, it has to be reliable, which means that it has to be accurate. To be complete, the information needs to contain enough substance to be a satisfactory decision basis. Finally, the information has to be delivered with timing. If the information reaches the decision maker at the wrong time, it might be irrelevant. (Mattsson, 2002)

Fawcett et al. (2008) explain that barriers to strategic supply chain management are among others inadequate information sharing and the unwillingness to share information, risks and rewards.

2.3.3 Forecasting
Forecasting is, according to Anupindi et al. (2012), a process in which future demand is predicted. There are four main characteristics of forecasts. Firstly, random noise will always be more or less present and therefore forecasts are normally inaccurate. Secondly, since the forecasts are normally inaccurate, the forecast error that shows the degree of confidence in the forecast should be provided. Thirdly, variability is reduced if the aggregated mean demand is considered instead of individual forecasts. Finally, short-term forecasts are more accurate than long-term forecasts since it is easier to predict what will happen in an instant than in the future. The three last characteristics are important to take into account when sizing safety inventory. (Anupindi et al., 2012)

Lapide (2000) claims that demand forecasting is a projection into the future of demand. Often, statistical methods are used in order to treat historical demand data and thus identify patterns that could be useful when creating a new forecast. The statistical methods can include time series analysis as well as causal forecasting. The latter makes it possible to take into account events such as marketing campaigns and weather. Demand forecasts are made frequently, e.g. once a month or once a week. (Lapide, 2000)
2 Theoretical Framework

2.4 Tools and Models for Logistics Investigations

2.4.1 The Case Analysis Framework

According to Oskarsson et al. (2006), it is important to find a well-structured way of working when developing and changing a company’s logistics structure. In the beginning of the project, the same authors mention that it is important to clarify the conditions, e.g. what the goal of the project is and which the available resources are. Oskarsson et al. (2006) continue that when the conditions are clarified, the next step is to do a situation analysis.

Taylor (1997) presents a case analysis framework that can be viewed in Figure 22.

![Figure 22. The Case Analysis Framework (Source: Taylor, 1997)](image)

Step 1 in the analysis model presented by Taylor (1997) is to do a situation analysis. This analysis is broken down into three parts: supply chain structure, supply chain performance and the business context. Analysing supply chain problems e.g. in the physical goods flow or the information flow is part of the supply chain structure step. The supply chain performance can be evaluated in three different aspects: the overall performance, the relative performance (benchmarking) and performance of the individual logistics functions. Finally, the business context consists of internal policies and the external business environment. (Taylor, 1997)

The second step, identification of main issues and problems, comprises two parts: categorise and prioritise. This means that all problems and issues that have been identified in step 1 should be listed, categorised and finally prioritised. (Taylor, 1997)
The third step is to generate alternative solutions. When generating these, Taylor (1997) suggests considering three levels: the specific functional issue, the corporate context and the supply chain context. Furthermore, Taylor (1997) points out that the most important thing when evaluating alternative solutions probably is to make a realistic analysis whether the company has the possibility to implement the solution or not. Taylor (1997) states that many solutions stay at the drawing board since the optimal solutions seldom are implementable.

Since the third step should lead to a decision, the fourth step consists of activities such as describing this solution and justifying the choice in terms of costs and benefits. Finally the last step includes the implementation of the solution, including practical questions such as resources needed, the timing of the implementation and how the costs and benefits will be monitored. (Taylor, 1997)

2.4.2 Process Mapping

**Process Maps and Their Use**

According to Davenport (1993), a process is:

“[...] a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs; a structure for action.” (Davenport, 1993, p.5)

Ljungberg and Larsson (2012) state that there are numerous process definitions. They point out that a process rather is a network of linked activities then just the linked activities themselves. Ljungberg and Larsson (2012) present the business process as a repetitively used network of linked activities that uses information and resources to create the value that satisfies a given need. Taylor (1997) states that supply chains normally have not been planned as one entity but are a combination of many different decisions taken individually at different times. Because of this, a business process map is an essential start when analysing a logistics flow since supply issues could be revealed (Taylor, 1997).

Anupindi et al. (2012) describe a process flowchart as a graphical representation of a process’ structure. The same authors state that flowcharts are useful when analysing or managing business processes. Due to Gardner and Cooper (2003) a map is a powerful tool since it describes a normally complex world in a visual way. Gardner and Cooper (2003) consider the effectiveness of a map as a direct outcome of how well it represents its system.

There are a lot of different notations when it comes to mapping business processes. Gardner and Cooper (2003) suggest that a map should have standardised icons, which can be established in e.g. universities or trade associations, to be considered useful. Oskarsson et al. (2006) explain that there exist a lot of different symbols and that it is important to use symbols that are useful and clear to the people that are going to use them. Also, Oskarsson et al. (2006) describe one common method, which describes material, and information flows in a simple way. These symbols are presented in Figure 23.
2 Theoretical Framework

A rectangle is used to describe an activity, a triangle to describe an inventory and a rhomb to describe a decision point. Furthermore, material flows are portrayed as continuous arrows and information flows as dashed arrows. Also, computer systems and paper document are represented by different symbols. (Oskarsson et al., 2006)

Olhager (2000) presents another set of symbols, which can be seen in Figure 24. In this case, a circle represents production, a triangle inventory, a square information processing and an arrow transport. Furthermore, Olhager (2000) describes how lead times can be written in the symbols to visualise how the different activities influences the system.

Oskarsson et al. (2006) state that it might be a good idea to start with a pretty rough process map and then rarefy it where this has to be done. Otherwise, a lot of work may be done on a very detailed level before anyone knows if this really is necessary. If flows in the map are quantified, it will be possible to determine which parts that are the most important to continue to work with. Lead time, delivery accuracy, delivery reliability and fill rate are common key performance indicators that can be used when analysing information- and material flows. (Oskarsson et al., 2006)

Popović et al. (2006) describe process maps as:

“ [...] a technique for graphic representation of logical steps in a process by considering activities (including duration, resources, constraints and costs), decision points, resources (types, numbers and costs), process delays,
Theoretical Framework

*Hierarchical decomposition (sub-processes) and organizational structure (e.g. departments).* (Popovič et al., 2006, p.115)

The authors further explain that the modelling elements are connected with links describing the process flow. The identified activities are placed in one or more departments, e.g. organisational units. In order to get a detailed view, processes can be broken into sub-processes. Depending on the goal with the modelling, the level of detail may vary. Bottlenecks in the process are found quicker if delays are clearly noted. Symbols for process mapping are represented in Figure 25. (Popovič et al., 2006)

![Figure 25. Process Mapping Symbols (Source: Adapted from Popovič et al., 2006)](image)

How to Create a Process Map

Ljungberg and Larsson (2012) describe different methods when it comes to process mapping. A “walk through” is a method where one or many people in the organisation basically follow the process through the different stages to map the activities and resources. Another method is called a “virtual walk through” and it means that a representative of each department or part of the process describes its role or the activities connected to its part of the process. The benefits of these methods are that they achieve a result pretty quick and that a lot of people do not need to learn mapping methodology. A disadvantage of the methods is that only the responsible of the mapping process will get a total understanding of the whole process. (Ljungberg & Larsson, 2012)

Creating a process mapping team is another method described by Ljungberg and Larsson (2012). This team should represent all parts of the organisation. In addition to a process map, this method results in an increased understanding of the processes in every department of the company. This method is probably the most common but it requires a lot of effort and time and it is vital that every member of the group is familiar with business process mapping methodology. The last method described by Ljungberg and Larsson (2012) is the “process design” method, which only is used when there are no formal processes, but similar individual ways of working. This method shall unify these ways of working and create one process.
When mapping a business process, Ljungberg and Larsson (2012) suggest an eight step method, which is presented below.

1. Define the purpose of the process and its start and end point;
2. Brainstorm the activities and write them down;
3. Arrange the activities in the correct order;
4. Merge and add activities;
5. Define object in and object out to every activity;
6. Control that all activities are connected to each other through the objects;
7. Control that the activities have the same level of detail;
8. Correct until a sufficient description of the process is achieved.

Furthermore, Ljungberg and Larsson (2012) conclude that one of the most common mistakes when doing business mapping is to get a too high level of detail and that the mapping process thus gets time-consuming.

Taylor (1997) states that when analysing the flow of products through the logistics pipeline, a good start is to make a flowchart from the origin of the products to the end customer. It is also important that the schematic picture is as simple as possible, e.g. supply chain diagrams should not be illustrated in a geographical map. The first step is according to Taylor (1997) to identify the fixed points in the supply chain and then categorise them into one of the following groups: manufacturer, upstream suppliers or downstream distribution units. Taylor (1997) describes that the second step is to chart the links between the organisational elements.

### 2.4.3 Pipeline Mapping

Making a supply chain map or pipeline map is a crucial beginning of trying to reduce the end-to-end pipeline time. A supply chain map can be described as:

“[…] a time-based representation of the processes and activities that are involved as the materials or products move through the chain. At the same time the map highlights the time that is consumed when those materials or products are simply standing still, i.e. as inventory.” (Christopher, 2011, p.134)

A supply chain map has vertical and horizontal time. The first one is process time and the second one static inventory time. (Christopher, 2011)
An example of a supply chain map is represented in Figure 26. Scott et al. (1991) describe how the length of the pipeline is the sum of the horizontal times while the volume is the sum of both horizontal and vertical times. The reason for why it is useful to make a pipeline analysis is that it makes it easy to identify where process or inventory time can be reduced. Often, reducing process time leads to a reduction of inventory time with about the same length. A pipeline map analysis can be made at any level of detail, depending on what is in focus. The authors also explain a very frequent problem that can be identified in the map. Often, high vertical lines can be distinguished on each side of organisational boundaries; however the horizontal time is quite short, just as in Figure 26 between the underwear manufacturer and the retailer. The explanation behind this is that both organisations are trying to compensate for uncertainty in the chain. Normally, only one of the vertical high lines is needed or at least both lines can be reduced of communication as well as information sharing increases between the two organisations. (Scott et al., 1991)

Christopher (2011) explains that:

“Mapping pipelines [...] provides a powerful basis for logistics re-engineering projects. Because it makes the total process and its associated inventory transparent, the opportunities for reducing non-value-adding time become apparent. In many cases much of the non-value-adding time in a supply chain is there because it is self-inflicted through the ‘rules’ that are imposed or that have been inherited. Such rules include: economic batch quantities, economic order quantities, minimum order sizes, fixed inventory review periods, production planning cycles and forecasting review periods.” (Christopher, 2011, p.136)

The author also states the following principle:

“[...] every hour of time in the pipeline is directly reflected in the quantity of inventory in the pipeline and thus the time it takes to respond to market place requirements.” (Christopher, 2011, p.136)
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2.5 Modelling and Simulation

2.5.1 Modelling

Models and Their Use

According to Law (2007), there are different ways to study a system. Firstly, a decision whether the system should be experimented with or whether a model should be constructed has to be made. Law (2007) states that a model can be mathematical or physical. If the model is mathematical, it can be an analytical model or a simulation model. In Figure 27 the ways of studying a system can be viewed.

![Figure 27. Ways to Study a System (Source: Law, 2007)](image)

A model of a system is a tool that can be used when trying to understand the system’s behaviour without experimenting with the real system. There are several reasons to use models instead of experimenting with the actual system. For example it might be very expensive to try some different settings on a machine or it might be dangerous to educate nuclear power plant operators in live situations. Another common situation is that the system does not exist when the model is created. In this case, a model is needed in order to understand how the system will work when it will be constructed later on. (Ljung & Glad, 2004)

In order to get a better understanding of functional relationships within a company as well as between a company and its surroundings, descriptive models can be built up. Examples of descriptive models that can be used in order to increase the understanding of a supply chain are forecasting models, resource utilisation relationships, cost relationships and simulation models. Optimisation models (also called prescriptive models or normative models) are prescribing (recommending) decisions, whereas descriptive models let the decision maker test and analyse by using the model and finally own judgment in order make a decision. (Shapiro, 2007)

Stock and Lambert (2001) defines modelling as a process in which a symbolic representation of a total system is developed. The authors also claim that a model should be useful to managers and correspond to the real world accurately. The purpose of a model is, as Stock and Lambert (2001) cited John H. Campbell’s “The Manager’s Guide to Computer Modeling” (1982), essentially:

“[…] to replicate reality and assess the behaviour of that reality if changes are introduced. A model supports, rather than replaces, the managerial decision-making process. By using a model we are able to establish a current situation and then play "what-if" games. This "what-if" ability is
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significant. It allows us to quickly consider many different alternatives and test the outcome.” (Stock & Lambert, 2001, p.173)

How to Create a Model
Ljung and Glad (2004) describe a three phase method for how to create a mathematical model:

1. Structure the problem;
2. Find basic equations;
3. Create a model of wanted type.

The first phase comprises the following steps:

- Split up the system in its sub-systems and identify the relationships;
- Determine which variables that are important and how they affect each other;
- Determine the level of complexity and degree of approximation of the model.

It is important to be well aware of the purpose of the model in the first phase. The second phase includes the below mentioned steps. (Ljung & Glad, 2004)

- Investigate the sub-systems and the relationships within each such by using basic equations;
- Introduce necessary approximations and idealisations.

For non-technical systems, basic equations might be missing and in that case hypotheses and innovative thinking may be useful. The third phase is a more formal one and the main part of it is to organise the relationships and equations found in phase two. Even though the model is practically finished after phase two, the third phase is necessary in order to create a model, which can be used for analysis or simulation. (Ljung & Glad, 2004)

Lundgren et al. (2003) describe a methodology for how to solve a problem with an optimisation model. The working process is depicted in Figure 28. Often, the real problem is complex and some of the components in it are not of interest, wanted or possible to include in the model. Several things have to be determined such as what is relevant or irrelevant, what is essential in the problem, level of ambition and appropriate limitations and simplifications. A prerequisite for a problem to be solved by optimisation is that the important parts of the problem are quantifiable. After all these steps, a simplified problem is obtained. (Lundgren et al., 2003)

Next, the simplified problem is transformed to an optimisation model. The model should contain variables, objective function and constraints. Further simplifications may be necessary due to limitations in available data or solvability. This step is followed by an application of an optimisation method, which leads to a solution. The obtained solution has to be evaluated and transformed into a decision support. Here, the solution is also verified and validated in order to ensure that the model provides the correct solution and that it represents the problem well enough. Sensitivity analysis is also made in this step. When all this is finished a result is achieved. (Lundgren et al., 2003)
When it comes to simplifications and assumptions, this can render large differences between reality and the model output. That is why decision-makers always should remember to use both simulation and analytic frameworks. (Hwarng et al., 2005)

2.5.2 Simulation

Law (2007) states that a simulation is a useful tool when analysing supply chains. The same author defines simulation as exercising a model numerically to see how the input affects the performance.

A computer simulation is the process of creating a mathematical and logical model of a real system and then testing the model in a computer in order to see in what way the system behaves when changes are made to its structure or environment. A model that imitates the behaviour of a system under a certain period of time is a simulation model. Using simulation is especially beneficial for complex flow systems. Simulation is not optimising in itself, simulation results due to different inputs need to be compared. Examples of what can be done by simulating are analysis of bottlenecks, long lead times and important level of tied up capital in order to achieve material flow efficiency as well as analysis of flexibility within a flow system. (Lumsden, 2012)

Simulation has several advantageous characteristics such as (Lumsden, 2012):

- Realism and Flexibility: It is easy to modify the model and change the level of detail;
- Accelerated time: Long simulations can be effectuated within a shorter timeframe than in reality;
- Dynamics: The real situation can be varied to a large extent and thus large variations in the flow can be observed and the characteristics of the model tested;
- Presentation: The simulation can sometimes be combined with graphical animations.

Stock and Lambert (2001) define simulation as:

“Simulation is a technique used to model a situation so that management can determine how the system’s performance is likely to change if various alternative strategies are chosen. The model is tested using known facts.” (Stock & Lambert, 2001, p.170)
Simulation does not give an optimal solution but it can help management to establish satisfactory solutions from a number of alternatives (Stock & Lambert, 2001). Persson (2010) argues that it is always interesting to include and analyse lead times and their variability, delivery accuracy as well as delivery speed and to identify bottlenecks when simulating supply chains.

### 2.5.3 Simulation Models

Cope et al. (2007) developed a generic simulation model, considered to be affordable as well as rapidly implemented. The authors claim that the supply chain environment has three main characteristics: it is subject to uncertain and high variability, it is dynamic and it is distributed. The first one is due to the different parts of a supply chain, all parts are related to each other and integrated, which results in an aggregated uncertainty. The second one, that it is dynamic, refers to changes in different levels of the supply chain. It can be on supply chain level, company level or companies’ elements level. The third one, that it is distributed, can be explained by the fact that supply chains are physically distributed and thus the information is distributed. This makes information gathering complicated and consequently analysis of the complete chain can be difficult to make. The authors state that:

> “The simulation methodology provides a means by which decision makers can obtain accurate results, given the model is valid, that take into account the uncertainty, dynamism and distributed nature of supply chain environments. With decision support tools based on mathematical models, spreadsheets or process map methodologies, decision makers are making decisions based on too many assumptions that very rarely hold true. [...] The bottom line is that not taking into account variability costs money. Averages cost money. They decrease companies’ economic value added by reducing sales, increasing the cost of goods sold, total expenses and increasing inventory.” (Cope et al., 2007, p.1888)

Moreover, regarding simulation models, Cope et al. (2007) state the following:

> “In addition, simulation models provide flexibility to allow for dynamism and distributed nature of supply chain environments. Simulations allow for easy variation of parameters within the model. The modified models can then be immediately run obtaining results sometimes in a matter of seconds. This is not always possible with mathematical modelling and process maps which sometimes require new models to be developed if the parameters change significantly. This increases the investment in time, money and resources that companies have to make when having to re-do models when parameters change.” (Cope et al., 2007, p.1888)

van der Zee and van der Vorst (2005) claim that:

> “The ultimate success of supply chain simulation [...] is determined by a combination of the analyst’s skills, the chain members’ involvement, and the modelling capabilities of the simulation tool.” (van der Zee & van der Vorst, 2005, p.65)
The authors state that if the three elements above are combined in an appropriate way, a realistic simulation model that is transparent and complete should be possible to create. Transparency is regarded as a very important factor for supply chains since they include different parties with own objectives.

2.5.4 Model Validation

In an Oxford dictionary, the verb “validate” is defined as “check or prove the validity or accuracy of” (Oxford Dictionaries, 2013). Dee (1995) defines model validation as follows:

“Validation of a computational model is the process of formulating and substantiating explicit claims about the applicability and accuracy of computational results, with reference to the intended purposes of the model as well as to the natural system it represents.” (Dee, 1995, p.4)

Regarding validation of simulation models, Law (2007, p.244) states that “validation is the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study”. Ljung and Glad (2004) point out that a model never is a true description of a system, however, if the model fulfils its purpose and can contribute to solve a certain problem, it is considered to be valid. Law (2007) states that no matter how much effort that is spent on model creation, the model will still be an approximation of the system. Absolute model validity does not exist according to Law (2007) who continues that increasing model validity beyond a certain level might not be cost-effective.

Ljung and Glad (2004) state that there is a tight relationship between the creation of a model and the validation of it since validation often includes reviewing all steps in the creation and maybe reject or improve parts of it. Rehman and Pedersen (2012) also point out that validation is an iterative process and that the model is tested and then adjusted until the final model is reached. Law (2007) exemplifies this and states that in many cases, validation unfortunately is done after the simulation model is created, and only if there is time and money remaining in the project.

According to Rehman and Pedersen (2012), models can be internally and externally valid. They continue that internal validation is linked to the mathematical abilities of the model while the external validation reflects how well the system is represented by the model. Rehman and Pedersen (2012) list three different validation methods: confirmative validation, sub validation and reference validation. They state that confirmative validation is the most common type of validation, where the model results are compared to empirical data. Sub validation signifies confirmative validation but for several subsystems of the model while reference validation is a theoretical validation method used when no empirics are available.

Law (2007) states that a model has to be revalidated if the model is being used for a new application since the new purpose may differ from the original one. According to Ljung and Glad (2004), it is vital to understand that every model has limits and that these are defined when the model is made. This means that a model never should be used outside its restrictions where it has not been validated since the results might not be accurate. However, Ljung and Glad (2004) continue, if a need of using the model outside its limits occurs, its credibility becomes important. This means that the user believes intuitively in it even though using it outside its limits.
If the manager, decision maker, client or whoever uses the model accept the results of the model as “correct”, the results are credible. A model might therefore be credible but not valid or vice versa. There are different ways of establishing credibility for a model, e.g. by obtaining the manager’s understanding for the model assumptions made or by demonstrating how the model has been validated. (Law, 2007)

In Figure 29, the relationships of validation, verification and credibility are shown. The solid arrows are the actions that are required to move from one position to another while the dashed arrows illustrate where the validation, verification and credibility enter the picture.

![Figure 29. Timing and Relationships of Validation, Verification, and Establishing Credibility (Source: Law, 2007)](image)

To increase validity and credibility, Law (2007) presents different techniques. For example, Law (2007) proposes that the modeller work in close contact with people who are familiar with the system. Furthermore, Law (2007, p.255) states that “it is extremely important for the modeler to interact with the manager on a regular basis throughout the course of the simulation study”. One reason to this is that the problem normally becomes clearer when the study carries on and another is that the manager’s interest in the study is maintained. Given that the system exists, Ljung and Glad (2004) claim that a model can be validated by comparing its results with the real output of the system (compare to the confirmative validation presented by Rehman and Pedersen (2012)). Law (2007) describes this validation method as the correlated inspection approach, which can be viewed in Figure 30.

![Figure 30. The Correlated Inspection Approach (Source: Law, 2007)](image)

Another thing to do in order to validate the model is to vary parameters and approximations in it and thus identify changes in the result. If the result changes a lot, the specific parameters or
2 Theoretical Framework

approximations should be further examined and their values should be more precisely determined. (Ljung & Glad, 2004)

Finally, Law (2007) describes the difference between validation and output analysis, which is important if the output of the model differs between simulations given the same input. This occurs when models with random samples from probability distributions are used. This difference is further described in Appendix III. The Difference between Validation and Output Analysis. Dee (1995) states that it is important to include validation documents in the validation part of a study.

No matter how much time and effort that has been put into creating a model, it is vital to remember that the system is the main thing, not the model. It is also important to never adapt reality to fit the model, but instead develop the model and taking new facts into account. (Ljung & Glad, 2004)
3 Task Formulation

In this chapter a brief introduction to the systems approach, and how this can be applied in the study, is given. The analysis model is a combination of elements from mathematical modelling and a logistics case analysis framework. Finally, all parts of the analysis model are broken down further into specific questions that are considered key in order to meet the purpose.
3 Task Formulation

3.1 The Systems Approach

According to Churchman (1973), there are five areas that have to be considered when investigating the meaning of a system: the goals and the key performance indicators, the environment, the resources, the components and the management.

The total goal of the system has to be clarified before the system can be defined. If this is not properly done, issues might arise within the rest of the system analysis. The key performance indicators tell how well the goal is accomplished. (Churchman, 1973)

The overall goal of the MDO department, which is presented in section 1.2.5 Global Outbound Logistics – MDO, is to improve and support the methods and tools for the global outbound logistics. The goal of this thesis is to provide MDO with one of these tools to contribute to more accurate decision making in order to reduce tied up capital while still ensuring a certain service level. However, the goal of the studied system is to provide the BUs/distributors with the forecasted number of units. Currently, the service level is measured and regarded as the main key performance indicator; however, this key performance indicator is not functioning very well since the real demand is not registered.

When talking about the environment of the system, Churchman (1973) explains that the fix restrictions outside the studied system should be considered as the environment of the system. The environment of the system is thus not only defined by physical borders but also by other systems around, whose traits and behaviour the studied system cannot affect. (Churchman, 1973)

The studied system’s environment is determined by the delimitations between the material supply and the production as well as between the RPC and the BU/distributor, see Figure 31. These delimitations imply that fluctuations in the material supply cannot be controlled by the system, even though the fluctuations might affect the system. Furthermore, forecasts will be included as an input to the system even if they are set outside the system boarders, meaning that the behaviour of the BUs/distributors are a part of the environment. Other fix restrictions on the system are customs clearance rules and other legal aspects in the involved countries.

![Figure 31. The Studied System](image)

Churchman (1973) states that the resources of the system are, in contrast to the environment, the things that the system can change and use to its advantage. Examples of system resources are employees, money and time. (Churchman, 1973)

In this particular case, the system’s resources are the people working in the production sites, in the RPCs and with pipeline management. Furthermore, the IT systems supporting concerned departments are considered being a part of the system resources.
The components of the system perform the actual activities in the system. These components can be compared to the tasks in a company and this breakdown is needed to evaluate whether the system works as it should or not. Furthermore, the components are used to find which tasks that actually are connected to the entire system’s key performance indicators. (Churchman, 1973)

The components of the system in this case are, on a high level, the production at the PRUs, the transportation and the assembly at the RPCs. Moreover, persons and resources working with supportive processes can be considered components of the system.

Finally, the management of the system take all the above mentioned parts into consideration when developing the company’s strategies. For example, the management define goals for the components and influence the system to decide how the environment and resources actually look like. (Churchman, 1973)

The management of the system in the study is in this case considered the MD department in general and the MDO department in particular, since they own several major processes and activities in the system.

### 3.2 The Analysis Model

The analysis model of this study builds on the case analysis framework model by Taylor (1997) presented in section 2.4.1 The Case Analysis Framework and the three mathematical modelling process steps by Ljung and Glad (2004), presented in section 2.5.1 Modelling. Since the model presented by Taylor (1997) is a very general logistics analysis model, it has to be complemented by a more mathematical one. However, only using a mathematical model in a logistics study might be too complicated since there are e.g. information flows that cannot be represented by mathematical relations. By combining these models, an analysis model that can handle the logistics problems and use the mathematical modelling methodology is achieved. The model is modified to suit this study by e.g. merging step four and five from the case analysis framework by Taylor (1997) into one. The analysis model is presented in Figure 32.
The first step in the analysis model is the process mapping. Process mapping is according to Gardner and Cooper (2003) a powerful way to show a complex world in a visual way and Taylor (1997) points out that a flowchart normally is essential when analysing a logistics flow. After the process mapping is done, the prerequisites of the model are compiled. It is due to Ljung and Glad (2004) necessary to structure the problem and determine which relationships the different elements in it have. When the basic equations are found, Ljung and Glad (2004) continue that the model should be created. Taylor (1997) states that the final solution has to be justified in terms of costs and benefits before it is implemented. In this study, the justification and the implementation are merged. This step includes a hand-over of the final product together with a justification of the simulation model containing advantages and drawbacks. In Figure 33, the analysis model is broken down further.
The process mapping step includes two main activities. Primarily, a high level mapping is done to see if any generalisations can be made early. This is according to Oskarsson et al. (2006) a pertinent way of working to avoid unnecessary mapping work. Also, the high level mapping is done where different flows are investigated to see if any of them have the same structure and thus do not need to be examined separately. When the high level mapping is done, a detailed mapping investigating activities, flows and relevant relationships in the logistics pipeline is conducted.

Secondly, the prerequisites of the simulation model are created. According to Lundgren et al. (2003), the real problem is often complex and some of the components are not essential to include in the model. Ljung and Glad (2004) point out that it is important to find the relationships between the variables in the system and that some approximations might be required. In the analysis model, the second part includes three minor steps: requirement specification, categorisation and prioritisation and identification of relationships. In the requirement specification, input from the taskmaster as well as from the process mapping is taken into consideration to create a realistic foundation for the simulation model development. When the requirements specification is defined, the processes’ and the activities’ relationships will be identified. Finally, they will be categorised into a reasonable level of detail before the prioritisations will be made to capture the most influencing parameters and activities, which will have a higher focus in the simulation model.

When developing the simulation model, the information from step two is used as a foundation. Ljung and Glad (2004) state that this step only should comprise the execution of the model. Lundgren et al. (2003) point out that the developing step constantly contains verification and validation to ensure that the model provides a correct solution. The third step in the analysis model is an iterative process.
where the simulation model is developed and continuously evaluated. The validation part also includes testing the model’s validity and reliability.

After the third step, the model and its way of working will be described, justified and delivered to the taskmaster. This part of the analysis model is more or less directly picked from Taylor (1997) and includes activities such as description and justification.

### 3.2.1 Process Mapping

**High Level Mapping and Flow Selection**

Oskarsson et al. (2006) suggest that it might be a good idea to start with a rough process map and then rarely it where this has to be done. Otherwise, a lot of work may be done on a very detailed level before anyone really knows if this is necessary (Oskarsson et al., 2006). In addition, Ljungberg and Larsson (2012) claim that a common mistake when doing process mapping is to get a too high level of detail, which is very time-consuming.

As has been found in the background of this study, this case includes several different physical and informational flows e.g. between the PRUs and the RPCs. It is of interest to try to find the common denominators in the flows. By finding these, it would be possible to decide whether some of the flows are similar enough that only one of them has to be mapped and thus the number of more detailed mappings would be reduced. The question 1.1 is thus of interest. (For further information about the similarity identification, see High Level Mapping and Flow Selection in section 4.2.5 Data Collection and Analysis and Execution.)

1.1 Which flows can be regarded having similar characteristics?

Also, while performing a high level mapping, possibilities to make simplifications within the different flows may be found. This is also something that would reduce the width of the detailed mapping further on. For example, if a transportation company carries out a specific part of the process, that part might not be of interest to map since it lies outside the Scania organisation and is sourced with certain performance criteria such as lead time. Hence, the following question is of importance to the process mapping.

1.2 Which other opportunities to simplification exist within each flow?

**Detailed Mapping**

Popović et al. (2006) describe the elements of a process map such as activities, decision points, resources, delays (bottlenecks), sub-processes, organisational structure and the links in between. In this case resources are not part of the study’s scope, mainly because costs are not analysed. However, activities and stocking points, flows, bottlenecks (question 1.9) and decision points are of interest.

The activities and their arrangements are important since this reflects the product flow, which is to be visualised in the simulation model. The material flows are important to map since this case is about buses and trucks that will be distributed all over the world. Given that many people are involved in the process and that they own and manage different parts of it, the information flows connecting them are interesting. Decision points, such as firm planned order, can be important in order to later on being able to create a simulation model that takes all main “fixed facts” into
account. In order to make the mapping as complete as possible and to gain an understanding for what is triggering the physical flow, it is also of importance in this case to map information systems supporting the flow, as well as non-system based or manual ad-hoc information flows. With the above in mind, the following questions become important:

- **1.3** Which activities and stocking points exist in the flow and in what sequence do they come?
- **1.4** Which are the material flows?
- **1.5** Which are the information flows?
- **1.6** Which are the decision points in the flow?
- **1.7** Which formal and informal information systems support the flow?

Persson (2010) argues that it is always interesting to include and analyse lead times and their variability, delivery accuracy as well as delivery speed and to identify bottlenecks when simulating supply chains.

If flows in the map are quantified, it will be possible to determine which parts that are the most important to continue to work with. Lead time, delivery accuracy, delivery reliability and fill rate are common key performance indicators that can be used when analysing information- and material flows. (Oskarsson et al., 2006)

Christopher (2011, p.134) even describes a supply chain map as “[...] a time-based representation of the processes and activities that are involved as the materials or products move through the chain. At the same time the map highlights the time that is consumed when those materials or products are simply standing still, i.e. as inventory.” This reinforces the importance of time when mapping.

Since a long lead time is one of the characteristics in this case, it is indispensable to not only explore what activities that are in the flow but also the length in terms of time of each of these. Without this, it would not be possible to simulate how the pipeline changes over time. In addition to the lead times, capacity limitations and bottlenecks are important components when simulating the pipeline. All flows have capacity limitations and these, depending on their values, play an important role for how products can move within the flow. As a result, the following questions need to be answered:

- **1.8** Which are the lead times and their variability in the flow?
- **1.9** Which are the capacity limitations in the flow?

The main thing to be visualised in the simulation model is the product volumes. For example different products may have different characteristics such as PRU origins or volume variations and this may affect how they can be treated in the model. Moreover, generalisation opportunities may prevail if some products can be clustered due to significant similarities or lack of need to be separated. For example, it is already known that several product categories such as CBUs, CKDs, refill and non-refill models are present in the flows. Thus, it is of value to investigate the question below.

- **1.10** Which products (or product categories) are in the flow and how do their volumes vary?
3 Task Formulation

3.2.2 Prerequisites to Model Creation

Requirement Specification
Ljung and Glad (2004) highlight the importance of being well aware of the purpose of the model before starting to develop it. Therefore, clarifying questions about the wanted model should be asked.

For a simulation model to be useful, the user types have to be identified. All users might not have the same needs, competence and requirements, therefore user identification and classification is required.

2.1 Which will the different user types be?

In order to be able to construct and design a simulation model that is well adapted to its users and their preferences, it has to be determined what the output should be and in what form it should be presented. Lumsden (2012) suggests that a simulation can be combined with graphical animations. It is already known that the simulation model should show volume levels at different stages in the process; however, it not decided how this should be visualised. For example, one alternative is to show numbers while another one is to create graphs displaying volumes in different activities or stocking points. This is why the following question has to be explored.

2.2 Which views and results should the model generate?

A central part of the requirements specification is to determine to what extent the simulation model is subject to change and to what extent it should be possible to modify it in order to represent the new reality. Creating a simulation model that is generic and flexible to a large extent may require a larger effort. As Cope et al. (2007) mention, one of the characteristics of the supply chain environment is that it is dynamic and thus always subject to change.

In this study, possible changes could potentially lead to elimination of activities or an adaption of the model to fit another flow that is not included in the original scope. Thus, the following question is of importance:

2.3 What flexibility should the model have?

Ljung and Glad (2004) claim that determining the level of complexity as well as the level of approximation of the model is one of the first things to do when creating it. Lundgren et al. (2003) emphasise that the level of ambition should be determined. Cope et al. (2007, p.1888) claim that “averages costs money” and “not taking into account variability costs money”.

It can be very time-consuming to find appropriate sources of data input to all stages if the granularity of the simulation model is too high. On the other hand, if the granularity is too low, the results generated risk to be too imprecise. Thus, it is important to agree upon how precise the simulation model should be. This leads to the following question:

2.4 What level of approximation should the model have and how complex should it be?
Categorisation and Prioritisation

Both Ljung and Glad (2004) and Lundgren et al. (2003) underline in somewhat the same way the importance of making approximations and simplifications in order to create models that are solvable but still give results that are aligned with the level of ambition and wanted degree of approximation.

The objective is to create a useful and as simple simulation model as possible. A step in this direction is to aggregate as many parts of the pipeline as possible while still ensuring the simulation model’s correctness. In order to realise this it is necessary to determine which parts identified during the mapping that are suitable for aggregation, which implies the following question:

2.5 Which activities and stocking points can be aggregated, i.e. where in the flow would it be most appropriate to position interfaces?

Also, Ljung and Glad (2004) state that variables and parameters are needed in order to define relationships later on. This justifies the question below.

2.6 Which are the variables and parameters in the system?

Another step in making a simple simulation model is to eliminate previously mapped parts that do not add any value to the model, i.e. the model would still give significant results without these elements. Lundgren et al. (2003) emphasise the importance of simplifying the real problem, among others by determining which parts that are relevant and essential in the problem and which that are not. This leads to the following question:

2.7 What has to be in the simulation model in terms of variables and parameters in order to obtain significant results?

In order to facilitate the identification of relationship process later on, it is also of importance to understand the characteristics of the variables and parameters such as their variability or if they are discrete or continuous. For example, it is known that the variable “truck volume” is discrete while lead time is continuous and this has to be taken into account in the model in order to avoid inaccurate output such as 2.55 trucks in a stock. Therefore the below stated question has to be answered.

2.8 What are the characteristics of the variables and parameters included in the simulation model?

A model requires input and generates output. Sources of input can vary, e.g. it can be a person’s own knowledge or an extract from an information system. If some required input elements are missing the model would not correspond to reality and it would probably be less useful. Thus, it is of importance to provide a list, with all the sources of input that can accompany the model and facilitate for the users. Therefore the below written question is useful.

2.9 Which are the sources of input to the simulation model?

Identification of Relationships

An important part when modelling, both according to Lundgren et al. (2003) and Ljung and Glad (2004) is to find the relationships and equations linking the different variables and parameters. In the Lundgren et al. (2003) case, it is about creating an optimisation model with variables, objective
function and constraints. In the Ljung and Glad (2004) case, it is about finding equations for the sub-systems identified or if this is not possible, stating hypotheses or use innovative thinking if no equations can be found.

In the study, it is clear that a mathematical part of the logistics analysis is present and that it therefore is necessary to identify and relate the variables and parameters. As an example, the volume level in the buffer is a variable while a capacity limitation is a parameter. Furthermore the capacity limitation might affect the volume levels downstream in the flow and hence it is crucial to find the mathematical link between these. This justifies the following question:

*2.10 How are the variables and parameters related to each other?*

### 3.2.3 Development and Validation of a Simulation Model

#### Development

The simulation model should represent reality in an accurate way and be easy to use. However, creating something that is user friendly might not be evident. In this case, it is e.g. important that the simulation model is easy to explain at a distance since the users are placed around the globe. The users also have different logistics competences and time to spend on learning how the simulation model works. The model should simply be made in a way that makes things easy to do right and hard to do wrong. A risk when a model has several different users is that they might succeed in modifying it in their way, which is not appreciated by the model owner since it might cause problems in the computational parts. Furthermore, erroneous data input might affect the computations negatively.

Persons with practical experience from model creation who could share their knowledge in the area would probably be a useful source of information in order to answer the questions below.

*3.1 What characterises a user friendly model?*

*3.2 What characterises a robust model?*

#### Validation

According to Ljung and Glad (2004) it is not hard to build a model but it is hard to verify that it is correct. It is vital to understand that every model has limits and that these are defined when the model is made. This means that a model never should be used outside its restrictions where it has not been validated since the results might not be accurate in that case. (Ljung & Glad, 2004)

With the above reasoning in mind, it becomes clear that testing the simulation model and making sure it is valid within its limits, is necessary before a hand over is made. The reason to this is that the simulation model will be part of the ordering decision made by the RPCs. Wrong ordering decisions can have large impacts on both customer service and tied up capital. Thus, it is vital that the simulation model generates correct output within its limits. It is also important that the simulation model is credible and thus well accepted as a useful tool by the users. This implies that the question below is of value:

*3.3 How good is the simulation model in terms of credibility and validity?*

### 3.2.4 Justification and Delivery

In the analysis model by Taylor (1997) the third step should lead to a decision and the fourth step include activities such as describing the solution and justifying the choice in terms of costs and
benefits. In this case, this could be translated into describing the advantages and drawbacks of the model before handing it over to its owner. Being aware of the advantages and drawbacks is crucial in order to use the simulation model in the right way and prevent mistakes. This justifies the questions below.

4.1 Which are the advantages of the simulation model?
4.2 Which are the drawbacks of the simulation model?
4 METHODOLOGY

In this chapter an introduction to the methodology approach is given at first. Second, relevant methodology theories are presented. These theories are alternated with how this study was conducted including how answers to the questions from the task formulation have been found. Finally, the credibility of the study is evaluated. Here, the authors highlight advantages and drawbacks of the study in a constructive way. The aim of this part is to give the reader a comprehensive view of what has influenced the study and what could have been made differently.
4 Methodology

4.1 Methodology Approaches

Jacobsen (2002) presents four methodology approach conflicts:

1. Inductive contra deductive approach;
2. Holistic contra individualistic approach;
3. Presence contra distance between the researcher and the object;
4. Qualitative contra quantitative study.

An inductive study starts with data collection whereupon relevant theories are collected to match the collected data (Jacobsen, 2002). The reason to this is that the researcher does not have any preconceived opinions about the data. When having a deductive approach, theories are processed and this leads to what kind of information that is going to be collected (Jacobsen, 2002). Björklund and Paulsson (2003) add the possibility that a study can be abductive, which means that it is both inductive and deductive and alternates between the both.

This study has primarily a deductive approach since the analysis has its base in a theoretical study where the analysis model is combination of several existing models. Furthermore, no empirical data collection was made until the theoretical framework was completed which means that all empirical data collection is done due to a combination of available theories and the problem background. The way of developing process maps follows the presented theories while the model execution to some extent is developed by the researchers.

The researchers campaigning a holistic view argues that study objects behave different in different environments and that this complex interaction between the study objects needs to be taken into account when collecting data. An individualistic approach means that every single study object is the most important data source and that the organisation is an aggregation of these objects and their efforts. (Jacobsen, 2002)

This study has an individualistic approach since the empirical data has been collected from every function within Scania separately. The answers and results have, in those cases where it has been possible, been triangulated but the result of the study can be considered a result of an analysis based upon aggregated data. One example of this is that every function was investigated separately whereupon the flowchart was developed. A reason to this approach is that the researchers considered that the functions act relatively separate from each other but in an established organisation and a fixed environment why they cannot act very different depending on the situation.

The distance between the researcher and the object is a central part when researching. The conflict originates from that the researcher has to be close enough to the object to understand its acting but far enough to not influence it. (Jacobsen, 2002)

In this case, the researchers have been working close to some of the main data sources, e.g. some of the interviewees, thus the study objects could have been influenced by the researchers. It can be considered that the functions themselves have not been affected by the researchers since the functions are vast compared to the number of individuals interviewed. However, as explained previously, the understanding of the system that the researchers have gained can depend upon how the interviews with the individuals in the functions were conducted. The researchers asked follow up questions if something was not clear and did not make or show any judgements or feelings during
the interviews in order to ensure that the interviewed person felt comfortable and answered honestly.

A qualitative study collects and analyses data as words. These studies are very flexible since open questions are asked and depending on the answers the researcher can ask follow-up questions that might change the direction. When doing a quantitative study, questionnaires are predefined and all results should be possible to analyse as numbers. This method requires that all answers can be pushed into these answer alternatives. (Jacobsen, 2002)

Björklund and Paulsson (2003) state that a qualitative study is appropriate when it is important to create a deep understanding in a specific subject while a quantitative study could be used when the data should be analysed numerically.

This study is qualitative since no empirical data has been analysed numerically. The methods used to collect empirical data are open interviews and focus groups, which the process maps, and ultimately the simulation model, are based upon.

4.2 THE METHODOLOGY OF THIS STUDY

Lekvall and Wahlbin (2001) state that it is important to know which elements a study contains before the study is planned. Also, they present a common working process when performing marketing research. In Figure 34 this working process is modified to suit this study and it can be considered appropriate even if it was not a logistics model when it firstly was formulated. Since the original method is a market research method, the activities are different. The way of visualising the research (as a “U”) is however in the original method and so are the links between the activities. In this particular case, there are no links between the theoretical framework and the analysis and execution since these do not correspond to each other. Note that the data collection and the analysis and execution to some extent are performed in parallel. However, the data collection starts before the analysis and execution start and ends before the analysis and execution end why they are depicted as following upon each other. Also, the analysis model depicted in Figure 33 at page 49 stretches from data collection to analysis and execution in Figure 34.
4 Methodology

4.2.1 Introduction

Lekvall and Wahlbin (2001) state that it is vital that the researcher and the taskmaster totally agree upon where in the problem the researcher enters the scene. If not, the expectations on the researcher may be too high and this might create some problems in the end of the study. According to Halvorsen (1992), the problem formulation is often set too wide in the beginning of a project. Another common problem is according to the same author that the problem formulation is described in a complicated way. Björklund and Paulsson (2003) state that the problem background has to be clear and explain to the reader which underlying elements that influence the study. Halvorsen (1992) concludes that a large part of a study is made when the problem is correctly formulated.

Halvorsen (1992) continues that it is important to spend some time formulating the problem since a well-planned problem formulation increases the possibilities of a successful result while Bell (2005) describes how important it is not to select a topic before the groundwork is properly done. Björklund and Paulsson (2003) mean that the purpose of the study has to be well defined and that it should be clear to the reader when the purpose actually is fulfilled. Halvorsen (1992) ends with that it might be necessary to reformulate the problem or set new delimitations as the project progresses.

In this study, the problem background was given the researchers when the study began and the overall purpose was set by the taskmaster. The given purpose was to “create a visual method and a tool to simulate different scenarios of demand and ordering for refill models at a RPC”. The complete initially given assignment can be found in Appendix IV. Initial Assignment from Scania.

In the beginning of this study, the researchers had to clarify the background of the problem and understand how different elements affect each other. The problem background originates from several interviews with Annmari Balázs, Pipeline Manager Regional Product Centres and supervisor at Scania, and internal Scania material. The purpose formulation, which is not the same as the original
one, is the output of numerous discussions between the researchers, the taskmaster and the supervisor at Scania.

Björklund and Paulsson (2003) point out the difference between delimitations and focus where delimitations are sharp lines that limit the study and a focus is an area within the delimitations where the study shall have its focus, see Figure 35.

![Figure 35. Purpose, Delimitation and Focus (Source: Björklund and Paulsson, 2003)](image)

According to Björklund and Paulsson (2003) it is also very important to declare which delimitations that might have been set up by the taskmaster. These kinds of delimitations are by Lekvall and Wahlbin (2001) identified as directives. Lekvall and Wahlbin (2001) describe how delimitations are set by the researcher to make the study more effective whilst the directives are given by the taskmaster due to relevance of the study.

Lekvall and Wahlbin (2001) break down the delimitations into two kinds, pertinent delimitations and delimitations due to cost or time reasons. Pertinent delimitations are made to get the correct balance between deep and width in the study and delimitations made due to cost or time reasons are made to get maximal output of the researcher’s effort. (Lekvall & Wahlbin, 2001)

The directives given in this study are presented in section 1.5.1 Directives. Some of these directives were already set by the taskmaster when the project began while others were set later during the problem background discussion.

The delimitations made in the study are presented in section 1.5.2 Delimitations. These were set primarily during the development of the simulation model since it was during this phase that many complications became evident. According to Lekvall and Wahlbin (2001) the delimitations should normally be determined at the very beginning of the study, before the field work starts. However, in this study, the field work (process mapping) revealed things that became delimitations in the subsequent step (creating the simulation model).

### 4.2.2 Theoretical Framework

According to Lekvall and Wahlbin (2001) it is necessary to do a literature review and to create a theoretical framework before the task can be formulated. This literature review includes models and theories published by others but it can also include already obtained knowledge about the organisation in which the researcher operates.

Halvorsen (1992) points out that it is important in the beginning of a project to create a clear picture of the problem area. The reason to this is, according to Halvorsen (1992), that the literature search might be too time-consuming if the problem area is not delimited enough. Bell
(2005) and Rumsey (2008) describe the importance of a search strategy in order to be able to identify the results that are relevant and to eliminate those who are not. Rumsey (2008) states that two of the key points when doing a literature search is to have a well-defined subject and a clear purpose and scope. A five-step process should, according to Rumsey (2008), be followed when searching for articles online:

1. Identifying search terms;
2. Limiting the search;
3. Developing truncations, wildcards and phrases;
4. Combining terms 1 (Boolean logic);
5. Combining terms 2 (using other connectors).

Identifying search terms contains finding topics and sub-topics that the literature search can be based on. Limiting the search includes defining e.g. language and publications dates while truncation, wildcards, and phrases include deciding if and how to handle words that might have different endings or alternative spellings. One example of a truncation is to use “organisatio*” instead of “organisation” and “organisations” since the first alternative includes both the others. Combining terms 1 contains activities such as deciding how words should be combined, e.g. with AND or OR. The last step is available in some databases where additional connectors might narrow the search further. (Rumsey, 2008)

Furthermore, Rumsey (2008) emphasises that the number of hits normally is very high when using only one search word. Therefore it is necessary to combine words when searching articles online.

According to Bell (2005), it might be good to start doing a literature search in a library by using the library catalogue and searching the shelves within and around the topic. Bell (2005) also describes that the reference lists in books and articles can give invaluable sources and be worth following up.

When creating the theoretical framework to this study, several literature searching methods were used. Initially, a non-structured Internet search was done to find inspiration and information about the different theoretical areas. However, the articles used in this study originating from the non-structured Internet search are all well-recognised articles that can be found in at least one of the business databases Business Source Premier or Scopus. When this search was done, a structured article search was made to find articles that could serve as a basis for the theoretical framework. This article search and its results are further presented in Appendix V. Structured Literature Search.

As a complement to the article searches, written sources such as books have been used. These books have primarily been found at the university libraries of Linköping University and the Royal Institute of Technology. When searching for literature, different shelves have been examined and these are presented in Appendix VI. Library Literature Search.

Furthermore, books used in courses at Linköping University have been considered adequate to be used when composing the theoretical framework. Finally, two other literature search methods have been used in the study. The first one was checking the references in already found articles and books to see if there could be anything of interest. All references have not been checked but in those cases where e.g. an interesting theory or a figure originates from another article, the source has been looked up. The other method used was to talk to the supervisor and her colleagues at Linköping University, the opponents and other students in order to get concrete tips about relevant literature.
The theories and models presented in the theoretical framework are all considered relevant to this study in one or another way. In those cases where the theories or models are not used in the task formulation or in the analysis, they are meant to serve as a logical base for the reader to be able to understand the problem situation and the reasoning later in the report.

4.2.3 Task Formulation

Lekvall and Wahlbin (2001) describe that there are three things that have to be investigated when defining the task: the orientation of the study, the content of the study and the delimitations of the study.

Lekvall and Wahlbin (2001) state that studies can be classified in four different orientation categories. A study that is explorative has its focus in contributing with fundamental knowledge. A describing study is mapping facts within e.g. a product area while an explaining study sorts out root causes and how they are connected to each other within an observed relation. Finally the predicting study gives forecasts of what could happen during certain circumstances. (Lekvall & Wahlbin, 2001)

One of the most important things when formulating the task is to define the content of the study. To do this, a problem background and a theoretical framework are needed. When formulating the task, the theoretical framework is applied to the problem background and the purpose of the study is concretised. When this is done, it is easier to conclude which aspects of the task that actually should be investigated. (Lekvall & Wahlbin, 2001)

Delimitations of the study should, according Lekvall and Wahlbin (2001), be defined before the field work starts. The delimitations of the study should not be confused with the directives of the study. Both these are further described in section 4.2.1 Introduction.

This study is a combination of a describing and a predictive study. The purpose basically consists of two parts, the process mapping and the simulation modelling, and they have different approach. The process mapping is a describing part of the study, where activities and relationships are investigated. The simulation part is not predictive by itself but it can be considered predictive in the sense that it contributes to predictive results when the model is implemented.

The task formulation follows the by Lekvall and Wahlbin (2001) presented way of working. In the task formulation of this study, the problem background is confronted by using theories presented in the theoretical framework. Different modelling methods and logistics analysis methods were combined into the analysis model of the study.

4.2.4 Methodology

Björklund and Paulsson (2003) describe how the methodology should show that the researchers know how a study is fulfilled. In the methodology, it should be clarified how the study was done, including which method choices that were done and why these choices were done. Furthermore a methodology reflection ought to be done where it is appropriate to reflect about what the study would have been like if other methods would have been used. (Björklund & Paulsson, 2003)

The methodology is built-up according to the above explained method. Initially, methodology theory describes how the different parts can be examined whereupon the way the study is conducted is
described. The overall objective with the methodology is to provide a description of how the study was made and thus it corresponds to the task formulation which describes what is required to find answers to in order to fulfill the purpose of the study.

4.2.5 Data Collection and Analysis and Execution

Björklund and Paulsson (2003) describe different data collection methods including, but not limited to, literature studies, interviews and observations. Collis and Hussy (2003) add focus groups as a data collecting method where opinions of a group are gathered. Furthermore Björklund and Paulsson (2003) state that there are two kinds of data, primary and secondary, where primary data has been created for the actual study while secondary data has been created earlier for something else. Still, secondary data can be used to the study but it is important to be aware of that the information might be angled (Björklund & Paulsson, 2003). Jacobsen (2002) points out that both qualitative and quantitative data can be secondary data and that this kind of data is commonly used when analysing.

Björklund and Paulsson (2003) describe the analysis as the part of the study where the empirics is analysed with input from the theoretical framework. The same authors continue that it is important to describe and motivate every element of the analysis well since this part normally contains the researcher’s perspectives. Björklund and Paulsson (2003) explain that readers should have the possibility to do their own review and draw their own conclusions.

In the general information gathering process, six process steps should be followed (Rumsey, 2008):

1. Analysing the question or the problem;
2. Defining the scope of the research and what information is required;
3. Identifying sources of that information (resource discovery);
4. Finding where that information is stored (resource location);
5. Gaining access to that information;
6. Ensuring that the information is (a) what is required, (b) reliable and (c) current.

Rumsey (2008) states that it is vital that the researcher fully understands what he or she is going to achieve with the research. In many cases, Rumsey (2008) continues, the topic and the problem are set by a third party and that these have to be clear to the researcher before starting the data collecting process.

According to Bell (2005), interviews can be very time consuming. On the other hand, it has a major benefit in its adaptability. Björklund and Paulsson (2003) present three different interview approaches: structured, semi-structured and unstructured interviews. The authors describe a structured interview as an interview that consists of questions asked in a strict order with fixed answer alternatives. Jacobsen (2002) names this kind of interview as a closed interview. An open interview is according to Jacobsen (2002) more like a normal conversation where the questions appear by time. This is what Bell (2005) and Björklund and Paulsson (2003) identify as an unstructured interview. Bell (2005) states that in most cases an interview ends up between the completely structured and the unstructured interview, an interview type Björklund and Paulsson (2003) name semi-structured.
Jacobsen (2002) describes open, individual interviews as especially appropriate when rather few objects are interviewed. Jacobsen (2002) and Bell (2005) both states that an unstructured interview normally gives a lot of valuable data but that it might be hard to analyse. Another case when an open interview is useful is when the researcher is interested in how the object registers and values different situations (Jacobsen, 2002).

Observations are useful when the researcher want to register what the study objects actually do, instead of what they are saying that they do (Jacobsen, 2002). They are also appropriate when the object’s behaviour in a context is the actual field of study (Jacobsen, 2002). Björklund and Paulsson (2003) state that observations in general might be very time-consuming but that they in many cases can give objective information. Bell (2005) describes that it is essential to decide what that should be observed and why it should be observed before the observation take place.

Focus groups are according to Collis and Hussey (2003) useful when opinions or feelings from a group are wanted. They continue that a group leader guides the group and stimulate them to discuss diverse topics. Collis and Hussey (2003) describe how to form focus groups:

1. Invite people with experience in the topic at a neutral place;
2. Introduce the members and discuss the purpose;
3. If possible, give visual examples of the subject matter;
4. Start with a broad discussion;
5. Allow the members to discuss the topics by themselves but ensure that everyone have the opportunity to contribute;
6. Use a prepared list of topics;
7. Enlist the help of observers and if possible, record the session.

Collis and Hussey (2003) continue that the focus group discussions should cover all the chosen topics and that they are one way to combine interviews and observations.

In general, data collection in this study can be considered following the six step process presented by Rumsey (2008). The literature review made in this study is handled separately in section 4.2.2 Theoretical Framework.

In the following sections, the detailed questions compiled in section 3.2 The Analysis Model will acquire additional information about how they were executed when conducting the data collection. In some cases, no data was collected since the questions are of analytical art. In those cases, the analytical way of working is presented.

In Figure 36 the data collection and analysis and execution is depicted. As can be seen, empirics i.e. data collection is alternated with analysis in order to make room for simplifications, generalisations and later on modelling. Note that this figure is not to be confused with the analysis model; it should be regarded as a support to the analysis model and it should make the data collection and analysis and execution parts more understandable.
Figure 36 illustrates how the high level mapping is pretty broad, how simplifications are done to give the authors the possibility to do a detailed mapping, how the detailed mapping is relatively narrow and how it has to be generalised before the modelling part can take over.

**Process Mapping**

**High Level Mapping and Flow Selection**

Before the detailed process map could be compiled, some general flow questions needed to be investigated. The reason to this was that the authors, during the problem background development, realised that some of the flows (from the PRUs to the RPCs) might be similar and that it would facilitate to simplify, both in terms of number of flows and in terms of number of processes and activities. For more information about the above mentioned flows, please refer to section 5.1 High Level Mapping and Flow Selection. The following questions where compiled:

1.1 Which flows can be regarded having similar characteristics?
1.2 Which other opportunities to simplification exist within each flow?

To get answers to the questions regarding the high level mapping, people with an insight in the overall process were interviewed. Annmari Balázs, Pipeline Manager Regional Product Centres, and Hans Ekman, Manager Global Outbound Logistics, were interviewed under semi-structured forms. The interview guide is presented in Appendix VII. Interview Guides and Focus Group Material. Together with the interviewees, this data was then evaluated with respect to the following criteria: activities, product types and which PRU that provides the RPC with products. These criteria where developed by the authors with its basis in the problem background formulation. As a complement to these, the interviewees had a possibility to add other criteria that they found relevant. The final criteria are presented in section 5.1 High Level Mapping and Flow Selection. The cells in Table 2 were filled in with a cross if the activity or stocking point, product type, component provider or additional criteria could be related to the RPC.
The sheet was used to evaluate if any of the RPCs have the same activities or stocking points or other similarities that could lead to simplifications. For example, if two RPCs have got crosses on exactly the same rows, they were regarded similar and only one of them needed to be further investigated. Even if the simulation model should include all the RPCs, it implies less work to map a few of them in detail and then generalise this over the others. The resulting sheet, Table 4, can be found in section 5.1 High Level Mapping and Flow Selection.

When the sheet was completed, which means that every RPC had been evaluated with respect to the criteria, qualitative discussions with the interviewees were hold to evaluate whether the simplifications were feasible or not. The reason to this was that some qualitative aspects might affect the simplification possibilities even if they are not noticeable in the evaluation sheet. When this was done, a decision was made regarding which pipelines to map further in deep.

**Detailed Mapping**

The detailed mapping questions should give a relevant picture of the material and the information flows, including additional information that might be necessary to build in to the simulation model.

1.3 Which activities and stocking points exist in the flow and in what sequence do they come?
1.4 Which are the material flows?
1.5 Which are the information flows?
1.6 Which are the decision points in the flow?
1.7 Which formal and informal information systems support the flow?
1.8 Which are the lead times and their variability in the flow?
1.9 Which are the capacity limitations in the flow?
1.10 Which products (or product categories) are in the flow and how do their volumes vary?
4 Methodology

Semi-structured interviews were carried out with Scania employees with knowledge in different parts of the entire flow. This virtual walk through was performed since it was impossible, or at least very hard, for the researchers to physically follow the flows. Interviews were held to give the authors the possibility to add extra questions depending on the answers. The results in the high level mapping lead to a deeper investigation of several flows, why the RPC responsible or the Pipeline Manager in these flows was interviewed. This was done via telephone since it was not possible to have a physical meeting. Furthermore, to identify persons with relevant knowledge, a discussion with the taskmaster was held. The authors stated that interviews with persons in every function along the pipeline were desired. This resulted in interviews with persons with good knowledge of the ordering process, the volume planning, the production and packing and the delivery process. Also, the responsible of the knock down (from now on KD) process, Fabio del Nery, who is situated in Zwolle and has knowledge of the entire process, was interviewed via telephone. In addition, Eduardo de Paula Silva who is Head of KD Development & Engineering and has a long experience from KD processes, participated in the interview. In this interview, it could be verified that all important functions had been covered. The interview guides are presented in Appendix VII. Interview Guides and Focus Group Material.

Finally, to confirm the picture of the pipeline and its generalisability, Ino Moberg (who is responsible of the RPC in Korea and Taiwan) was interviewed. The reason that Moberg was chosen was that he has long experience of the complete pipeline process and that the RPCs within his control were not mapped in detail. The interview guide is presented in Appendix VII. Interview Guides and Focus Group Material.

After the interviews, to get a complete picture of the entire pipeline, a focus group with process responsible was set up. This focus group followed the by Collis and Hussey (2003) described steps (except from step 7) and the focus group material is presented in Appendix VII. Interview Guides and Focus Group Material. The invited were all working at the MD department but with different tasks and processes and the reason to invite them was to get a comprehensive view of the pipeline and to connect the different functions to each other, since the interviews only gave detailed pictures of the functions separately. First, every participant in the focus group was given a blank paper. On this, everyone was told to illustrate their views of the product and information flows. Second, a short presentation of each function and the mapping was made and this served as a basis of discussion. The goal of the focus group was to create a common view of the process mapping, i.e. merge each participant’s view with the previously view created during the function mapping.

A combination of the presented flowchart symbols in section 2.4.2 Process Mapping was used to show the flows in a visual way. In Figure 37 the symbols used in this study are presented. These symbols were chosen since none of the presented sets alone met the needs. Furthermore, the eight step method created by Ljungberg and Larsson (2012) and presented in section 2.4.2 Process Mapping was used when making the flowcharts. One flowchart per studied function and RPC flow was developed.
To be sure that no activities had been neglected, the output from the preceding activity should be equal to the input of the following one, in terms of units. This was controlled by putting the detailed maps together to cover the whole process. This complete process map was also verified by the focus group presented above.

**Prerequisites to Model Creation**

**Requirement Specification**

The requirements specification is valuable since it serves as the basis for the entire simulation model and the simulation model creation. The questions related to the Requirement Specification stated in section 3.2.2 Prerequisites to Model Creation were the following:

- **2.1** Which will the different user types be?
- **2.2** Which views and results should the model generate?
- **2.3** What flexibility should the model have?
- **2.4** What level of approximation should the model have and how complex should it be?

To get adequate answers to these questions, a minor focus group with the taskmaster was set up. This focus group was held once a week during the whole study. Especially question 2.4 was investigated throughout continuous interaction with the taskmaster during the study. The answers to questions 2.1-2.3 are presented in section 6.1 Requirements Specification whilst question 2.4 affects the entire chapter 6 Prerequisites to Simulation Model Creation and chapter 7 Development and Validation of the Simulation Model.

Input to this focus group was the problem background as well as the developed flowcharts from the detailed mapping. The questions above were the main points of the focus group but the input data was needed to create realistic requirement specifications. The focus group material is found in Appendix VII. Interview Guides and Focus Group Material.

**Categorisation and Prioritisation**

To simplify the model creation, possible aggregations of activities from the detailed mapping had to be investigated. This means that it has to be decided where in the process the interfaces between different activities should be placed. Therefore the following question has to be answered:
2.5 Which activities and stocking points can be aggregated, i.e. where in the flow would it be most appropriate to position interfaces?

By associating the activities and stocking points with several criteria, the activities and the stocking points could be evaluated. In Table 3, the evaluation sheet is presented and when filled out it led to a decision about which activities and stocking points that could be aggregated. The criteria were compiled by analysing the detailed mapping above.

For example, one criterion could be "capacity limitations" and in which order they appear in the pipeline. This results in a difference in where the stock is held depending on if the lower capacity is situated before or after the higher one when aggregating the activities and stocking points. Thus, an activity or stocking point with a lower capacity can be aggregated with the following one since the aggregation does not "move the stock" in the flow chart. In the other case (with a higher capacity on the first activity or stocking point) the aggregation will lead to a "movement of the stock" from being situated in between the activities or stocking points to be in front of the first one (since the total capacity is equal to the lower one). However, since several criteria were used, these cannot be isolated from each other since they affect the activities and stocking points in different ways. This means that the evaluation sheet is used as a base when aggregating activities and stocking points but not as a direct solution. The actual activities and stocking points and the criteria used in this evaluation are presented in section 6.2.1 Aggregation of Activities and Stocking Points.

Table 3. Evaluation Sheet for Aggregation of Activities and Stocking Points

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<td>Activity or Stocking Point [h]</td>
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</table>

Once the activities had been evaluated they were clustered together chronologically with respect to the evaluation and thus an aggregation was obtained. The final results of the aggregation can be seen in section 6.2.1 Aggregation of Activities and Stocking Points.

When the activities and stocking points had been aggregated an investigation of variables and parameters was conducted. The first question to find an answer to was:

2.6 Which are the variables and parameters in the system?

Question 2.6 was answered by using the information received during the high level and detailed mapping. A general list with main groups of variables and parameters was set up. The next question to answer was the following:

2.7 What has to be in the simulation model in terms of variables and parameters in order to obtain significant results?

The analysis answering this question was conducted by combining the aggregated activities and stocking points with the groups of variables and parameters. This resulted in a long list of variables and parameters. Each variable and parameter was then analysed by taking into account the
evaluation made in Table 3 and thus a decision could be made whether the variable and parameters should be included in the model or not and if so, which role it should have. The result of this procedure can be seen in Table 10 in section 6.2.2 Identification and Choice of Variables and Parameters to Include in the Simulation Model.

Question 2.8 and 2.9 were investigated in parallel with the detailed mapping. The results can be seen in Table 11 in section 6.2.3 Sources of Input.

2.8 What are the characteristics of the variables and parameters included in the simulation model?

2.9 Which are the sources of input to the simulation model?

Identification of Relationships

To find the basic equations is due to Ljung and Glad (2004) the phase where, in case of a non-technical model, the researchers could use innovative thinking. However, the pipeline has some mathematical relationships that are relevant and the question from the task formulation is:

2.10 How are the variables and parameters related to each other?

This question was considered answered when sufficient relationships had been compiled. In the part Detailed Mapping some parameters and variables were quantified but the relationships between them needed to be calculated as well. An example of such a relationship could be that the inventory level in an inventory at time t+1 is the inventory level in the inventory at time t adding the input volume and subtracting the output volume. In this section, the relationships and characteristics of the parameters and variables were arrayed. This work was of analytical art and it was conducted by following the flowchart from the start activity to the end activity, assuring that every relationship along the pipeline was arrayed. This step is strongly characterised by logics.

Development and Validation of a Simulation Model

The development and validation process was to a large extent an iterative process. The only clear milestones were to start by creating a structure for the model and after that defining the content and the interfaces. The authors have chosen to present this way of working and these steps in detail and in chronological order in chapter 7 Development and Validation of the Simulation Model since the development is strongly connected to the analysis and the resulting simulation model.

Development

In the development part, the questions below needed to be answered.

3.1 What characterises a user friendly model?

3.2 What characterises a robust model?

These questions were investigated when interviewing Mats Abrahamsson, Professor in Logistics Management at Linköping University, and Fredrik Stahre, Lecturer in Logistics Management at Linköping University. Both have long experience of logistics simulations. The interview with Fredrik Stahre was conducted after the detailed mapping while the interview with Mats Abrahamsson was made at the very beginning of the project. Both interviews were open such and the reason to this was that the interviewees were considered being experienced and that semi-structured interviews might limit the discussion and thus important areas could be neglected.
4 Methodology

After this, the execution took place, which means that the actual creation of the model was performed. Ljung and Glad (2004) claim that the model is basically finished when the problem is formulated and the basic equations are set up. The third step in the model is therefore depending on the specific problem, which implies that this part of the study was an innovative phase where analysing skills and innovative thinking of the authors were being tested. Therefore, there are no direct methods that can be applied to this part of the study and the authors have created the simulation model by using the output from the Prerequisites to Model Creation part and by taking the answers to question 3.1 and question 3.2 into consideration.

Validation

Finally, the following question has to be investigated before the model can be considered complete.

3.3 How good is the simulation model in terms of credibility and validity?

The question above was to some extent examined during the simulation model creation. As Rehman and Pedersen (2012) point out, validation is an iterative process and the model should be tested and then adjusted until the final model is reached. The taskmaster was involved in the development and validation process in order to increase the credibility of the simulation model. However, a final validation was also made after the development was finished to ensure the simulation model’s functionality. During the final validation, the supervisor at Scania carried out own tests of the simulation model and came up with input regarding the performance and user-friendliness. Included in the final validation was also a sensitivity analysis where different values were used to examine the simulation model’s validity. Both small and large values and combinations of these were used to see how the simulation model reacted. Furthermore, data from one RPC that was not part of the detailed mapping was used as input to ensure the simulation model’s generalisability.

Dee (1995) explains that it is important to attach validation documents to the study. Therefore, all tests that have been made are either presented in section 7.2 Validation or in Appendix VIII. Sensitivity Analysis.

Justification and Delivery

When the model is developed, it is important to understand the strengths and weaknesses of it. The questions asked where:

4.1 Which are the advantages of the simulation model?

4.2 Which are the drawbacks of the simulation model?

All advantages and drawbacks were summarised in order to provide the users of the model with clear user directives. The summary contains advantages and drawbacks that the creators of the simulation model have discovered during the development and validation process.
4.2.6 Conclusion and Discussion

In this part, the researchers conclude upon study and discuss which consequences the result may have. It is important that the researchers, with help of their analysis, draw their own conclusions. Furthermore, it is central that a discussion about the study’s generalisability is included and that the results are related to the problem background and previously presented models and theories. (Björklund & Paulsson, 2003)

In the conclusion, the authors evaluated whether the purpose of the study was fulfilled or not. Then, a recommendation regarding the use of the simulation model was developed. In the discussion the generalisability of the study was assessed and areas for further research were suggested.

4.3 Credibility of the Study

Jacobsen (2002) states that the empirics have to fulfil two demands:

1. The empirics have to be valid;
2. The empirics have to be reliable.

When talking about validity, the empirics can be internally valid and externally valid. Internal validity means that the investigators measure what they actually wanted to measure while external validity deals with whether the results are transmittable from the specific measurement to the organisations as an entity or not (Jacobsen, 2002). Jacobsen (2002) points out that reliability stands for that repeated measures with the same instruments should give the same results and Easterby-Smith et al. (1991) note that reliability primarily is a matter of stability. Björklund and Paulsson (2003) visualise the validity and the reliability and compare this with a dartboard where high validity is achieved when the darts hit the bull’s eye and high reliability is achieved when the darts are gathered at the same spot. In Figure 38 the validity and the reliability are visualised. In the left picture of the figure neither reliability nor validity are achieved. In the picture in the middle, the reliability is high but the validity is still low. In the last picture, both reliability and validity are high.

Björklund and Paulsson (2003) add that except a study’s reliability and validity it is important to examine the study’s objectivity. Jacobsen (2002) describes a phenomenon that is called investigation effect, which can be compared to the objectivity. This phenomenon arises in observations, interviews and other data collection methods. Jacobsen (2002) continues that it is not possible to get rid of the investigation effect since different researchers register a situation in different ways. Björklund and Paulsson (2003) propose a couple of ways to increase a study’s objectivity. One of these is to declare and clarify all the choices that have been made to give the reader a possibility to take a stand regarding the situation.
Easterby-Smith et al. (1991) state that there are several advantages to use different methods in the same study. Due to same authors, this is called triangulation and they identify four different kinds: theoretical, data, investigator and methodological triangulation. Björklund and Paulsson (2003) point out one additional type of triangulation, evaluation triangulation, which means that the same data set is evaluated by different researchers. Easterby-Smith et al. (1991) and Björklund and Paulsson (2003) both depict data triangulation as a triangulation method where data is obtained from different data sources. Furthermore, Easterby-Smith et al. (1991) explain that investigator triangulation is where different persons collect data whereupon it is compared. Also, Easterby-Smith et al. (2001, p.134) exemplify theoretical triangulation as “borrowing models from one discipline and using them to explain situations in another discipline”. Collis and Hussey (2003) mean that it might be hard to use investigator triangulation when not being a part of a research team. They continue however that data, theoretical and methodological triangulation should be used sometime when doing research. Collis and Hussey (2003) carry on that it is valuable to use both quantitative and qualitative methods when collecting data.

In the following sections, the credibility of each part of the study is evaluated.

### 4.3.1 Introduction

The problem background was given the researchers when the study started. This can be considered relatively reliable since the taskmaster is eager to get the study properly done. The purpose of the study was developed by the researchers together with the taskmaster and the supervisor at Scania. One interesting aspect of the purpose formulation would have been if the RPCs were involved in this part. The purpose would maybe not have been the same if they would have had a chance to affect the study in an early stage.

Regarding the directives and the delimitations of the study, the taskmaster had a great impact on the direction of the investigation in the beginning. If the researchers have had a more open task, the delimitations would maybe have been different. Even though the directives were relatively tight, some delimitations were set. However, the researchers have required motivations to every directive to assure the rationale behind them.

### 4.3.2 Theoretical Framework and Task Formulation

While doing the literature search, the researchers have made a thorough investigation about which database that hosts the most articles relevant to the study. However, it cannot be established that the other databases do not host any articles of interest. Also, qualitative decisions have been made regarding the selection of which articles that are relevant to the study. If another person would repeat the literature search, other articles might have been chosen but this would probably not have affected the theoretical direction of the study. Furthermore it is important to point out that any articles found via the initial non structured search were controlled in well-known databases and that articles found via other articles are considered being well-recognised.

The articles have, together with the books found in the libraries, served as a basis for the theoretical framework and thereby also the task formulation. The libraries host several for the topic relevant books, however other interesting books could have been on loan or not hosted by the used libraries. In some cases, books have been ordered from other libraries but this only happened when specific books were requested. No one can guarantee that the libraries host all the relevant literature but
they can be considered to host significant literature to cover the studied area. Furthermore, books used in courses at Linköping University have been used in this study.

Different sources were used in the theoretical framework, normally on the same subject area, to confirm or overthrow theories and methods. Thus, data triangulation has been present in this section. Diverse definitions are presented to give the reader the possibility to compare them and to achieve a comprehensive view of the study area. In some cases, the presented subject areas are not directly relevant to the study but needed to give the researcher as well as the reader the entire picture of the area within which the simulation model should work.

The task formulation is a direct output of the problem background and the theoretical framework. The analysis model is the result of a combination of two models from different disciplines used on an area in between them. The two parts that were merged into the analysis model of this study are considered to be suitable in their proper contexts of general logistics analysis and mathematical modelling. The authors believe that the combination of these two models has turned out to be a well-functioning solution for this specific case.

4.3.3 Data Collection and Analysis and Execution
The interviews were all except one performed by the same interviewers where both persons asked questions and noted the answers. Both interviewers were asking follow-up questions. All answers were written down and sent to the interviewees afterwards to confirm that everything was correctly understood. However, some of the interviewed did not return a confirmation and in these cases the authors considered that the information was correct.

Some criticism can be raised against how the interviewees were chosen. Since the researchers did not know the entire company and its departments, the taskmaster had to be involved when setting up the interviews. In fact, the taskmaster suggested persons to interview, why it cannot be assured that a complete picture of the flows was achieved. However, since the taskmaster still is eager that the study and the simulation model are properly done, it can be assumed that the taskmaster did not disregard potential interview objects due to dissent.

The main data that has been used originates from the interviews that have been made specifically for this study. Thus, the majority of the data used is primary data. Only some background and company information derives from secondary sources. As Collis and Hussey (2003) explained, it is valuable to use both quantitative and qualitative methods when collecting data. However, this study has mainly been based upon qualitative data, which thus can be regarded as a weakness. Data triangulation has been part of the empirical study, since interviews first were made with representatives from different functions and RPCs and thereafter verified through interviews with KD-process responsible and representatives from other RPCs. This increases the credibility of the process mapping part.

The framework for the study was well followed. However, the translation of the information from the process mapping and the mathematical relationships into a Microsoft Excel based simulation model is not as structured and easy to repeat as the rest of the study. During the creation of the simulation model, problems were taken care of when they occurred which basically means that no predefined way of working was followed.
4 Methodology

A usual way of testing simulation models is to run historical data and try to judge whether the real output is similar to the simulation models output. However, this has not been feasible during this study due to several reasons. One of the reasons is that demand from the BUs/distributors is never completely registered. Instead of running historical data to test the simulation model, three other validation tests have been done. More information about these can be found in section 7.2 Validation. It hard to judge whether the simulation model will work in 100 % of the cases but with respect to the tests that have been done, it is reasonable to establish that the simulation model works.
5 \textbf{PROCESS MAPPING}

In this chapter the findings made during both the high level and detailed level process mappings that have been conducted are presented. Pure empirics are alternated with analysis in order to go from a wide perspective including all flows, then determine which flows that can be considered representative and finally generalise and apply the findings from the representative flows on the remaining flows. At the end of the chapter, verifications are presented that confirm the findings.
5.1 High Level Mapping and Flow Selection

The flows that can be regarded as similar are the ones to Malaysia, South Africa, South Korea, Taiwan and Thailand, while the Russian flow is considered different (Balázs, 2013; Ekman, 2013). Below, the analysis leading to this result is presented. In Table 4, the evaluation sheet from section 4.2.5 Data Collection and Analysis and Execution is completed.

Table 4. Completed Evaluation Sheet for the High Level Mapping

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Malaysia</th>
<th>Russia</th>
<th>South Africa</th>
<th>South Korea</th>
<th>Taiwan</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity or Stocking Point</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Handling</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CBU Assembly</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CKD Packing</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transportation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Buffer Inventory</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>KD Assembly</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Bodybuilding</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FGI</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Product Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buses</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CKD</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Refill</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Non-Refill</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>PRU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luleå</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Oskarshamn</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>São Paulo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Södertälje</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Zwolle</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

The criteria that finally were used were activities or stocking points, product types and PRUs. Balázs and Ekman did not have any further criterias they thought were necessary to use in order to evaluate the RPCs’ similarities and differences.

All of the RPCs have the same order handling process, which is globally controlled from Södertälje. Included in this process are e.g. receiving orders and planning these in the production. South Korea is an RPC that receives CBUs and these are assembled before they are shipped overseas. However, the other RPCs’ CKD kits need to be packed why these activities can be equalised. (Balázs, 2013; Ekman, 2013)

When the products are packed or assembled they are transported to the market where the RPC is situated, whereupon they are put in a buffer inventory. After this, the CBUs in South Korea are body built and the CKDs in the other RPCs are assembled. These activities can be equalised as well but the RPC in Russia differs since both these activities are performed. Finally, every market has an FGI. (Balázs, 2013; Ekman, 2013)

All markets have trucks but South Korea and Russia do not have any buses entering the market via the RPCs. Remark that the bus-notion here only refers to the bus chassis and not complete buses.
with both chassis and bodies. As described before, only South Korea has CBUs while the other markets have CKDs. Every market also has both refill and non-refill flows. (Balázs, 2013; Ekman, 2013)

Regarding the PRUs, these flows were evaluated more in depth. The reason to this was that the authors did not know that component PRUs in some cases deliver directly to the RPCs. Firstly, as can be seen in Table 4, there are deliveries from Luleå, Sweden, to the RPC in Russia. Secondly, Oskarshamn, Sweden, delivers to Russia as well as to Malaysia and Thailand. Södertälje delivers to every RPC except to South Africa or South Korea, while Zwolle delivers to every RPC. Finally, there are deliveries from São Paulo to South Africa. In Table 5 the PRU part from Table 4 is further broken down and components as well as CBUs and CKDs are marked. (Balázs, 2013; Ekman, 2013)

<table>
<thead>
<tr>
<th>PRU</th>
<th>Malaysia</th>
<th>Russia</th>
<th>South Africa</th>
<th>South Korea</th>
<th>Taiwan</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luleå</td>
<td>Components</td>
<td>Russia</td>
<td>CKD</td>
<td>CKD</td>
<td>Components</td>
<td></td>
</tr>
<tr>
<td>Oskarshamn</td>
<td>Components</td>
<td>Components</td>
<td>CKD</td>
<td>CKD</td>
<td>Components</td>
<td></td>
</tr>
<tr>
<td>São Paulo</td>
<td>CKD</td>
<td>Components</td>
<td>CKD</td>
<td>CKD</td>
<td>CKD</td>
<td></td>
</tr>
<tr>
<td>Södertälje</td>
<td>CKD</td>
<td>Components</td>
<td>CKD</td>
<td>CKD</td>
<td>CKD</td>
<td></td>
</tr>
<tr>
<td>Zwolle</td>
<td>CKD</td>
<td>CKD</td>
<td>CKD</td>
<td>CKD</td>
<td>CKD</td>
<td></td>
</tr>
</tbody>
</table>

Luleå, Oskarshamn and Södertälje deliver components directly to Russia while Zwolle delivers the CKD Kit. Oskarshamn delivers components directly to Malaysia and Thailand and the CKD kits are shipped from Södertälje or Zwolle. Moreover, CBUs and CKDs are shipped from São Paulo, Södertälje and Zwolle according to Table 5. (Balázs, 2013; Ekman, 2013)

In addition to this, components are delivered from the component PRUs to the PRUs according to Table 6.

<table>
<thead>
<tr>
<th>Component PRU</th>
<th>São Paulo</th>
<th>Södertälje</th>
<th>Zwolle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luleå</td>
<td>Components</td>
<td>Components</td>
<td>Components</td>
</tr>
<tr>
<td>Oskarshamn</td>
<td>Components</td>
<td>Components</td>
<td>Components</td>
</tr>
<tr>
<td>São Paulo</td>
<td>Components</td>
<td>Components</td>
<td>Components</td>
</tr>
<tr>
<td>Södertälje</td>
<td>Components</td>
<td>Components</td>
<td>Components</td>
</tr>
</tbody>
</table>

Luleå, Oskarshamn and Södertälje all deliver to both Södertälje and Zwolle while São Paulo delivers to São Paulo. (Balázs, 2013; Ekman, 2013)

In Figure 39, the RPC flows are summarised. Please note that there are raw material flows to both the component PRUs and the PRUs (CBU Assembly/CKD Packing) but that these are not taken into consideration since they are not a part of the studied system.
In Figure 39, some of the components that are produced at the component PRUs are named to the left. It is important to understand the difference between the truck assembly and packing in Zwolle and the bus packing in Södertälje. As can be seen in Figure 39, the cabs from Oskarshamn are delivered to the truck assembly and packing in Zwolle, if not delivered directly to the RPCs in Russia, Malaysia or Thailand. Furthermore, the side members from Luleå and the axles, engines and gearboxes from Södertälje are delivered to both Södertälje and Zwolle and directly to the RPC in Russia. São Paulo has its own component PRU delivering all components.

Even though the flows seem to have a lot of differences, some simplifications can be done. Firstly, the ways of working at the PRUs in Södertälje, Zwolle and São Paulo are considered the same. This means that if a mapping is done in e.g. Södertälje, it can be considered valid even in Zwolle and São Paulo. Secondly, the component flows from the component PRUs directly to the RPCs, have all shorter lead times than the associated CKD kit from the PRU to the same RPC. In addition, component disturbances are considered rare. Thus, it is logical to make the assumption that the CKD kits are the only factor that has to be taken into account, and the component flows can be neglected. (Balázs, 2013; Ekman, 2013)

With these simplifications in mind, the component PRUs can be excluded from the detailed mapping. Furthermore, even if only Malaysia and Thailand have got exactly the same crosses in Table 4, South Africa, South Korea and Taiwan are regarded to have similar flows as the two first mentioned RPCs. The reason for this is that it does not matter which PRU that supplies the RPCs, e.g. in terms of
activities and stocking points. Furthermore, the product types do not matter either since the trucks and buses do not initiate major different ways of working, only different lead times. South Korea could potentially cause problems since this is the only flow with CBU’s instead of CKD’s but as mentioned before, the activities and stocking points regarding these different products can be equalised. Therefore, the only RPC that differs from the others is the one in Russia and the reason for this is that both assembly and bodybuilding are performed and that this potentially can cause extra problems contra the other ones. When choosing which RPC to map in detail, Russia is an obvious choice. In addition to this, South Africa will be further investigated. The reason to this was that this study was conducted in Sweden, which is situated in the same time zone as South Africa. This made the contact easier and since the five RPCs are judged to be equal, no further considerations had to be done. In Figure 40, this decision is summarised.

The flows that will be further investigated and mapped in detail are shown in Figure 41. As can be seen in the figure, the component flows are excluded as well as the flows to other RPCs and the two chosen ones. This implies that the PRU in Södertälje also is excluded. Nevertheless, since this study is conducted in Södertälje and since the PRUs are considered to have the same ways of working, the PRU in Södertälje is mapped in detail. The sub departments in section 5.2 Detailed Mapping are thus, except for the RPCs, all based on the situation in Södertälje and this is then applied to the other PRUs.
5.2 DETAILED MAPPING

As can be read in section 4.2.5 Data Collection and Analysis and Execution, the functions in the following sections (5.2.1-5.2.6) were chosen after a discussion with the taskmaster. Furthermore, the mapped functions are all, except for the volume planning (from now on KXV), parts of the order-to-delivery process, which means that they are directly connected to the order or the product. KXV is however included since their output is the number of slots that each RPC gets in the production. This number of slots can be modified in some cases, e.g. if an RPC really needs additional capacity. Other functions that have been found during the mapping have not been investigated in detail if they are only supportive functions that do not affect the product lead time. The following functions cover all the relevant parts according to the KD-process responsible, Fabio del Nery.

5.2.1 KXV

KXV is a part of Franchise and Factory Sales (from now on F&F, see Figure 1, page 5) and their process starts at the delivery request deadline once a month. However, before this deadline, the BU/distributor has made a forecast in SWIP (Scania Web Information Provider) and the RPC have controlled the forecast and put an order suggestion in SWIP depending on the current stock and pipeline status. The order suggestions are regarded as the market demand input to the KXV process. (Wijkström, 2013; Wigermo, 2013)

When the demand has been collected, KXV confirms this with the market responsible. After this, the analysis part of the KXV process starts. The volume analysis includes taking the order book and the order intake into consideration as well as filling rate, stock levels, the overall market situation and if there are any big deals in the pipeline. This is done separately for buses, trucks and engines. The demand and volume analysis results in a volume proposal. A coordination meeting is then held with
the KD markets where the markets get information about the volume proposal. After this, there is a market demand planning meeting (from now on MDP meeting) where the segment (bus, truck and engine) directors and the head of F&F participate. The output from this meeting is a decision regarding which market volumes that are needed the following twelve months. (Wijkström, 2013; Wigermo, 2013)

The market volumes are then sent to the central planning for further analysis. This analysis includes determination of production capacity corresponding to the market request. One week later, a production planning meeting (from now on PP meeting) is held, where the market side and the production side together decide the production plan for the coming twelve months. The decided volumes are now allocated and distributed per market and communicated back to the RPCs and BUs/distributors via FAIN (Factory Availability Indication). In Figure 42, the KXV process is shown. (Wijkström, 2013; Wigermo, 2013)

![Figure 42. The KXV Process](image)

In total, the process takes two weeks. One of these weeks is between the delivery request and the MDP meeting while the other one is between the MDP meeting and the PP meeting. Thus, the final volume distribution goes pretty fast. Also, the KXV process is made once a month, why the decided twelve months plan is updated every month. (Wijkström, 2013; Wigermo, 2013)

In FAIN, the RPCs and the BUs/distributors can see how many slots they have left in production during every period. However, the RPCs might place more orders than they have got allocated. In those cases, the orders are placed at the same market’s following period. These orders can however be produced anyway if the other markets do not fill their slots. (Wijkström, 2013; Wigermo, 2013)

This general forecast-to-allocation process is confirmed by de Paula Silva (2013). It can be concluded that the KXV process does not affect the product lead time since this process is conducted once a month and takes two weeks. Since the last decided plan is covering the coming twelve months, there is always a decision regarding the market allocations. However, it is important to understand that the market allocations can be updated in near time and that this affects the possibilities to make the required orders.
5 Process Mapping

5.2.2 Order Office

The order office is situated in Södertälje and it takes care of all incoming orders. The one who places an order, in this case an RPC, communicates its order by using an order system. In the order system the wanted product has to be specified, the desired delivery date has to be stated as well as the delivery address. A first verification of the model’s compatibility is done in the order system used, however this is a quite rough one in which the vehicle is checked in three levels. This means, fictitiously, that e.g. it is verified that the gearbox is compatible with the engine, which in its turn is compatible with the axles and so forth. When the order has passed it arrives at the order office in Södertälje. (Karlsson, 2013; Tulldahl, 2013)

An important criterion for the RPCs when ordering is that they should place orders as batches that are multiples of three. This implies that the RPCs can order batches of three, six, nine vehicles etcetera. (Balázs, 2013)

The first thing that is done at the order office is that different systems verify that the desired delivery date and the address are correct and then compatibility verification is made. This verification is more fine-meshed and tests up to seven levels of compatibility compared to the three levels made earlier. If something turns out not to be buildable, or if the date or address are not correct, then the order is returned in COW (Central Orders on the Web) and the one who placed it has to take action. Thereafter, the correction is returned and the order can continue its way in the order office’s process. Normally, if deviations occur, the KPI (Key Performance Indicator) mean is eight hours, which means that it takes eight hours in general to correct an order. If the order was not subject to a deviation, i.e. it passed all the verifications; it takes about 15 minutes for it to pass right into the order book. In this case, nobody is involved at the order office and the order is only treated automatically in different systems. (Karlsson, 2013; Tulldahl, 2013)

Once a correct order is received, it continues to the order allocation system. This system takes into account all possible limitations in production volume and components such as the production capacity in volume per PRU, market reservations and transportation calendars among others. Many departments are involved in updating limitations in this system. The vehicle is, after treatment in this system, given a slot in the production. After the allocation step, IACOB (Integration & Common Order Book) sends out a confirmation to an order system that forwards an order confirmation to the customer and the order continues its way and enters the order book. Here, all orders are listed. (Karlsson, 2013; Tulldahl, 2013)

Once a week a meeting called batch closed is held. During this meeting it is decided which volumes and which models that should be produced, but not in where or in which sequence. Three days after the batch closed meeting, the order gets a so called Status 1 which basically means that the order is handed over to the production department and they can start their work with the production order. (Karlsson, 2013; Tulldahl, 2013)

In Figure 43 the whole order process is depicted.
The order process takes thus between three to eight days if the order is placed with production start in the next part period.

### 5.2.3 Production and Packing

The production and packing process starts when the order office has closed the batch and sent the models and volumes to be produced in the next period to production and packing. Firstly, the local planning department is planning the sequence in which the trucks and buses should be produced. Then, every order gets a final production date. When this is done, a mix report is sent to the KD engineering, the component PRUs, the delivery function and to the pre-assembly. Packing instructions are then received from the KD engineering and the batches are released (which include printing lists and labels), whereupon the packing process can start. (Malki, 2013)

The packing process consists of two different ways of working. Components and sequence parts arrive pre-packed and they are quality controlled. Sequence parts are e.g. cables that are produced for just a specific truck or bus. Parts (e.g. screws and nuts) and pre-assemblies (e.g. ventilators that are assembled to a specific truck or bus) are picked from storage or directly from the assembly line. Before they are picked, the pallets need to be built, which is done in the packing area locally. In Södertälje, the current capacity of pallets building is twelve buses per day. If the need rises above twelve buses, this part has to be outsourced. When the pallets have been built, the parts are picked and quality controlled. The quality control includes counting the parts that can be counted and weighing the low value but high volume parts. (Malki, 2013)

Since the RPCs are ordering batches in multiples of three, the work load in the packing process varies a lot. If a big batch of e.g. twelve buses is packed, it goes much faster than packing four batches of three. In addition, the fill rate in the pallets is improved with larger batches. (Malki, 2013)

The packing instructions from the KD engineering include how to pack the containers taking parameters such as weight distribution and simplicity when unloading into consideration. The parts and the preassemblies are pre-mirrored before they are mirrored at the yard together with the components and the sequenced parts. They are then loaded into the container. When the container is closed, the production and packing process ends and the delivery function is notified. (Malki, 2013)

The whole process takes maximum 19 days. When the sequence is planned and the production orders are mixed, every order gets a production slot from one to five days from this date. When the batch is released, there are six days until the product is loaded in the container. If there are no material constraints, this time does not differ. If any articles in a kit are missing, the container is
5 Process Mapping

normally loaded and sent anyway. Then, the lost article can be flown to the RPC instead. However, since this might be very expensive, communication between the production and packing and the RPC is very important in order to keep costs low. If any containers are shipped without every article, Scania try to send the article with the next shipment instead of flying the article to the RPC. In some cases, the specific truck or bus need to be built directly when it arrive and the article thus need to be flown in. (Malki, 2013)

In Figure 42 the whole production and packing process is depicted.

![Figure 42. The Production and Packing Process](image)

To conclude, the production and packing process takes between 14 and 19 days, depending on when in the sequence the order is planned.

5.2.4 Delivery

The delivery processes are conducted at every PRU, i.e. the persons working with the delivery process in Södertälje have their equivalents in e.g. Zwolle. The KD-related delivery process starts when the sequence planning sends out a mix report. The mix report contains dates, batches and chassis numbers. When a chassis number is created, the date when the packing should be done is set. The closing date is set to be a couple of days later. The mix report is sent to among others the delivery department and KD engineering. When the KD engineering has created packing instructions for the KD-goods, it is clear how many containers that are required in order to pack the goods. This technical specification is the sent to the delivery department and they can book the containers. The transportation is also booked since the dates are known. (Kaski, 2013)
When the containers have been packed and closed they are transported to the harbour. All batches have to be in the harbour at the closing date. However, the batches should be packed and ready already at the confirmed release date (from now on CRD), which occurs at the day before closing date at the latest. Documents that are required for the export have to be completed at the closing day at the latest, but often they are made earlier. During the closing day the shipping company is not allowed to move the goods since Scania is handling customs clearance that day. Every destination country has a fixed closing day weekly. (Kaski, 2013)

In order to keep the customer informed about the status of the order, the delivery department sends out a KD-Follow-UP (from now on KDFU) weekly or e-mails in order to communicate the estimated time of arrival (from now on ETA). Currently, all KD-monitoring is made in the KDFU-files since the normal delivery system, SOLEIL (Scania Outbound Logistics Exchange Information on Line), cannot handle this type of orders. However, a project named GOLS (Global Outbound Logistics Solution) with the objective to develop a system that is able to handle all types of orders has been initiated. (Kaski, 2013)

Once the goods has arrived at the destination port the responsibility for it is handed over to the order office, which take care of the importation, and the delivery department is no longer involved. The delivery department reports the actual delivery date (from now on ADD) in the KDFU. (Kaski, 2013)

The delivery function is thus working in parallel with the production and packing and the only direct lead times to the product are the transportation to the harbour and the customs clearance. However, these lead times vary a lot depending on the PRU and the country from which the goods is shipped. Also, there might be different choices of departure port depending on the goods.

### 5.2.5 RPC Russia

The RPC process in Russia starts when the BU/distributor makes a forecast for the next twelve months. The RPC evaluates the forecast with respect to the current stock, what is in the pipeline and the sales behaviour, i.e. how many of the forecasted products that already have a specific customer. When this is done, KXV sets the market allocations and send them back to the RPC and the
BU/distributor. The pipeline manager at the RPC then decides which orders to make and sends the decision to the order handling at the BU/distributor. The pipeline manager takes the forecast, the current stock level, the booking situation at the BU/distributor (i.e. how many trucks that are already booked by end-customers as well as delivered trucks) and the market situation into account when determining the order volume of each model. Currently, the total volume to produce is quite fixed, however the pipeline manager decides how to distribute the volume between the different models. Russia never order batches larger than twelve trucks; other possible batch sizes are three, six and nine. The whole process is depicted in Figure 46 and, as can be seen in the figure, the order handling part at the BU/distributor is illustrated to be separated from the BU/distributor to simplify the figure (which is not the actual case). Finally, when the order is confirmed, the BU/distributor is notified and forwards this confirmation to the RPC via e-mail. (Goldina, 2013)

When the order has been sent, there is a standard lead time of one week to plan the production at the PRU. Then it takes another four weeks before the products can be packed. The packing process (including making the exportation documents) takes one week and the transportation lead time from Zwolle to Russia ranges from thirteen days up to three weeks. The components are sent directly from the component PRUs (as has been stated in section 5.1 High Level Mapping and Flow Selection) and their lead times are shorter than the kit from Zwolle. Today, when computing the pipeline, the kit (i.e. the parts packed in Zwolle) lead time is used. However, the components are sent to match the arrival of the kit, why a deviation in the component flow might affect the production capability. The buffer stock before the production line should thus contain two weeks of production why a small deviation is acceptable. (Goldina, 2013)

The kits that are shipped from Zwolle arrive at the harbour in St. Petersburg for customs clearance. Normally, this procedure progresses without any complications. Sometimes, the documents are wrong from the PRU but this is ordinarily detected during the shipment and the documents are corrected before arrival. If the buffer stock at the RPC is full, the kits can be stored in the harbour. This is however relatively expensive and the RPC tries to bring all material to the RPC as soon as possible. The components are never stored outside the RPC area. (Goldina, 2013)

The buffer stock is situated directly at the RPC and the production sequence can be changed on a pretty short notice. The production takes about one week, including assembly, body building, final inspection and quality control. All vehicles are both assembled and body built and are, even if there are two separate production lines, always performed directly after each other. When a vehicle is finished, it is placed at the FGI where the RPC has a target to store two weeks’ demand. At this very moment, about 60 vehicles are stored in the FGI, which corresponds to approximately two and a half weeks’ consumption. Currently the total lead time for order to delivery at the RPC is around 15 weeks. (Goldina, 2013)

There are two capacity limits. The first one is due to local regulations that currently limit the production to seven trucks per day. The regulations are due to Russia entering World Trade Organisation and introducing a scrapping fee, something that affects the profit of using an RPC instead of importing already finished trucks. The second one is the market allocation from KXV. The production is not very flexible regarding volume changes why temporary changes are handled by producing the units in the buffer stock. If the changes are not temporary, the production speed
needs to be lowered. Today, the RPC has two refill models and they represent 70% of the total volume. (Goldina, 2013)

![Process Mapping Diagram]

**Figure 46. The PRC Russia Process**

### 5.2.6 RPC South Africa

What triggers the process to start at the RPC in South Africa is an incoming forecast from the BU/distributor. Once a week, an order meeting is held during which several persons representing e.g. pre-sales, sales and the RPC are attending. During this meeting, the stock levels, the pipeline volumes and the forecast are taken into consideration whereupon an order suggestion is sent to SWIP. After this, KXV can see the total demand (taking both forecast and order suggestion into consideration) and decides slot levels per market, see section 5.2.1 KXV. When the allocation decision is sent back, the order meeting decides how much to order. Please note that the KXV process is performed once a month and that the order meeting is held every week why the exact activities differ. (Svensson, 2013)

When the orders are made, the RPC can do nothing but wait. If the order is faulty, it has to be corrected. When the order is correct, the RPC can do nothing but wait and follow the shipment. When the containers arrive at the port, the responsibility of the goods is transferred to the RPC from the delivery function. The RPC in South Africa gets help with the importation documents from a transportation company who also informs the RPC if there are any transportation problems etcetera. If there are any deviations, the goods can sometimes get stuck in the harbour for a while. However,
the aim is to transport it to the buffer stock in Johannesburg as soon as possible. The harbour of arrival is situated in Durban. (Svensson, 2013)

The goods are then transported to the buffer inventory in Johannesburg. The stock levels differ a lot depending on e.g. the season but this is considered to be the main buffer stock in South Africa. From this buffer stock to the assembly plant, which is also situated in Johannesburg, it only takes a couple of hours. There is also a buffer at the RPC, which provides the line with vehicles. When a truck has been assembled, it is stored at the stock yard (FGI) until the BU/distributor picks it up. When the BU/distributor has picked the truck, they are responsible for it and the risk of the truck is transferred to them. The RPC process ends and the BU/distributor has to pay within ten days. The buses are never stored at the stock yard since they will be body built. This is controlled by the BU/distributor and performed by some local actor. (Svensson, 2013)

In Figure 47, the whole RPC process in South Africa is depicted.

At this very moment, the RPC is assembling about 35 vehicles per week to the FGI. The maximum capacity is considered to be around 170 vehicles per month during shorter periods. Furthermore, it is hard to find staffs that are educated why it is important to keep the ones that already work at the RPC. Due to this, it is vital to have a smooth flow through the assembly. Also, the in South Africa there are sometimes problems with strikes, normally in September and October, why the RPC tries to increase the stock levels before this period starts. (Svensson, 2013)
South Africa is served with trucks from both São Paulo and Zwolle and with buses from São Paulo. Furthermore, there are variations in the overseas transportation and deviations are not unusual. (Svensson, 2013)

5.2.7 The Complete Process

In Figure 48, the whole pipeline process is shown. As can be seen in the figure, the process is triggered by the forecast from the BU/distributor (step 1). This forecast serves then, together with the stock levels, as the basis for KXV. When KXV have got all their information from the central planning, a market allocation is made. The RPC then sends the order to the order office. However, the orders are sent once a week and the forecast-to-market allocation process is performed once a month. The steps 1 to 8 in the figure are thus performed in parallel with the other process and do not affect the lead time from the order to a delivered truck or bus. The allocations per market (step 8 in Figure 48) are necessary to know when placing an order but the process behind these allocations does not influence the total lead time.

The actual pipeline process can therefore be considered to start when the order arrives at the order office (step 9). Under the circumstances that the wanted production start is in the next part period, the order stays at the order office between three to eight days, depending on when the batch is closed. Of course, an order can be placed e.g. one year before the production start, and in that case,
the order stays at the order office for one year and then for three to eight days depending on when the batch is closed. When the orders are sent to the production and packing, they are sequence planned and get a final production date (step 11). Depending on how the production is mixed, this date can differ from one to five days. The whole production and packing process takes maximum 19 days. This means that the actual production and packing take about 13 days, since the last days is the delivery day and the first one to five days depend on the sequence planning.

The delivery function is working in parallel with the production and packing. They get the technical specification from the KD engineering (step 13) and then book the empty containers (step 14) that will be packed as well as the shipment. This means that, if everything goes as it should, their only lead time addition is the transportation to the harbour and the outgoing customs clearance. The transportation to the harbour lead time differs a lot since the PRUs are situated at different places (step 18). After the overseas shipment, whose lead time are fix in themselves but vary a lot depending on the PRU and the RPC, the RPCs take over when the goods arrive at the destination port. If the goods are transhipped during the shipment or not, does not matter since Scania negotiates a fix lead time from the transportation company. However, as Svensson (2013) reported, the lead times are not that fix as they should be and deviations exist. It is also important to understand that the overseas shipments are sent maybe once a week or even every second week. Due to this, the goods might be stored in the harbour, under the transportation company’s responsibility, during the period of time before the ship leaves.

When arrived at the port, the goods are stored in the port or transported to the buffer inventory. From there, the kits are delivered to the assembly line in the production. Regarding the buffer inventory, a difference between Russia and South Africa can be seen. In Russia, goods might be stored in the harbour while the goods in South Africa are transported directly to the buffer inventory. Russia then has one buffer inventory in front of the assembly line while South Africa has two. However, the first and the second buffer inventory in South Africa are situated close to each other and can be considered as one, with an transportation time on a couple of hours.

Another difference is seen in the production at the RPCs. Russia has both assembly and body building where South Africa only has an assembly line. Nevertheless, all vehicles in Russia are both assembled and body built and these activities can be seen as one production line. When the buses and trucks have been assembled, they are delivered to the BU/distributor (step 20). In Figure 49, the common RPC flows can be viewed. Please note that only the material flow process is depicted in Figure 49 since the order handling activities are basically the same.

According to del Nery (2013) and de Paula Silva (2013), the main bottleneck in the KD flow is the assembly at the RPC. del Nery (2013) states that the capacities in the PRUs are quite high. de Paula
Silva (2013) continues that the lead time within every PRU is about the same if there are no disturbances.

The focus group confirmed the big picture of the complete pipeline process; however, some points were discussed that had not been brought to light during the interviews with every function in the KD flow. For example, transportation, especially shipping, is sometimes subject to limitations in capacity. The group confirmed that production in general runs without any major deviations in lead time. Also, forecasts were considered being an important source of error and overseas transportation shows the highest deviation risk. (Eriksson, Hedman, Lindgren, 2013)
In this chapter important input to the model creation phase is presented. Several aspects that are important to be aware of and areas that the creators should have knowledge in are explored. For example, discoveries made during the mapping process are broken down into parameters and variables, activities and stocking points are aggregated and simplifications are made. In addition to this, many user-related issues are treated and model requirements set, everything in order to create a clear recipe of what is to be created and minimise the development time for the simulation model.
6 Prerequisites to Simulation Model Creation

6.1 Requirements Specification

6.1.1 User Types
The focus group identified two main users: Pipeline Management in Södertälje as well as Pipeline Management at the RPCs. S&S could also be considered as one of the users but only in terms of getting the possibility to see some results if presented by the Pipeline Management. The S&S users are therefore not considered to be one of the parties that should be taken into account when creating the simulation model. Further discussions led to the decision that the Pipeline Management users in Södertälje should have the same characteristics and needs as the Pipeline Management users at the RPCs. To conclude, only one user type that should be taken into account when creating the model exists and that is the Pipeline Management. However, someone, probably the Pipeline Manager in Södertälje, will be assigned the administrator role. The administrator has access to all parts of the simulation model in order to being able to modify it if needed.

6.1.2 Views and Results
The outputs from the simulation model were discussed with the focus group and three main such were determined. The first one is what the pipeline looks like, i.e. which volumes that can be found at different stages of the pipeline. The second and third ones are part of the first one, namely buffer and FGI levels; however, these should be visualised even more clearly than the rest of the pipeline since these are considered key in the decision making. Some of the interviewees also expressed explicitly the need of visualisation of the volume levels in the buffer inventory and FGI; Moberg (2013) was one of these.

6.1.3 Flexibility
Several criteria were identified within the focus group regarding the simulation model’s flexibility. Below the results from the discussions are stated:

- The simulation model that the RPCs are to use should be generic. This means that in the study only one single simulation model will be created but each RPC will receive a copy of it and populate it with RPC specific data. A risk of divergence within the RPCs’ specific simulation models over time exist and therefore the locking and protection of parts of the sheets will be necessary as well as a very clear layout, facilitating the use of the simulation model and reducing the need for larger modifications that are not expected to be a built-in option.
- One RPC should not have the possibility to simulate that goods from different PRUs arrive, i.e. it is not possible to simulate different lead times for different goods. In reality some of the RPCs are supplied from several different PRUs with different lead times. Thus each RPC will have to make an approximation of the lead times.
- The granularity of the simulation model should be at least weekly.
- Regarding the number of activities in the simulation model, this should not be modifiable.
- If it would be possible to handle batches it would be nice to have but not necessary.

6.1.4 Level of Approximation and Complexity
One of the main objectives of the simulation model is to increase the users understanding of the pipeline and the effects certain order volumes have on it. Thus, the simulation model should rather give hints about whether stocks are increasing or declining and about when this will happen so that
pipeline managers easily can understand the effects of their decision making regarding order placement volumes. Due to the long lead times, re-planning points at the RPC and the fact that most parts of the model will depend on manual input, making a simulation model that is too exact seems unnecessary. For example, this basically means that it is not of relevance to know that there are exactly five units of model A in week X in the buffer inventory. However, it is of relevance to see that the volume level of model A in the buffer inventory has increased from about fifteen units to about twenty between week X and week Y. It is important to remember the purpose of the simulation model, which is to increase the understanding of the pipeline as explained above and not e.g. telling a BU/distributor exactly what will be available in X months.

### 6.2 Categorisation and Prioritisation

#### 6.2.1 Aggregation of Activities and Stocking Points

In Table 7, main activities and stocking points directly related to the order-to-delivery process are listed. Each activity has been assigned a lead time or a description of it. Note that it is not necessarily just this specific activity lead time but the time it takes before the next activity can be performed. This means that additional activities can be going on in parallel or that other supportive activities can take place in between. Thus, the activities stated are considered to be main milestones in the process.

The various lead times are associated with a certain risk in terms of deviation. The authors have made judgements based upon the interviews whether the risks can be considered as low, medium or high. Also, discussions regarding capacities have been conducted which made it possible to pinpoint the activities and stocking points that can be considered having an important capacity limitation. Since each market is assigned a certain number of slots in the production and this number is communicated to the RPC before they place their orders, the main capacity limitation is already taken into account before the arrival of the order. This explains why the number of activities that has a capacity limitation is small, even though they have limitations in reality.

<table>
<thead>
<tr>
<th>Activities and Stocking Points</th>
<th>Criteria</th>
<th>Lead Time</th>
<th>Lead Time Deviation Risk</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Arrival and Checking</td>
<td></td>
<td>&lt; 1 day</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Order Allocation</td>
<td></td>
<td>&lt; 1 day</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Order Book</td>
<td></td>
<td>1-5 days</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Batch Closed</td>
<td></td>
<td>&lt; 1 day</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Sequence Planning etcetera</td>
<td></td>
<td>4-9 days</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Batch Released</td>
<td></td>
<td>4 days</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Packing</td>
<td></td>
<td>2 days</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Loading</td>
<td></td>
<td>1 day</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Transportation to Harbour</td>
<td>Relatively short, depends on which PRU</td>
<td>Low</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Customs Clearance</td>
<td></td>
<td>&lt; 1 day</td>
<td>Low</td>
<td>-</td>
</tr>
<tr>
<td>Overseas Shipping</td>
<td>Relatively long, depends on which PRU and RPC</td>
<td>Medium</td>
<td>Limited</td>
<td></td>
</tr>
<tr>
<td>Customs Clearance</td>
<td>Relatively short, depends on which market</td>
<td>High</td>
<td>Limited</td>
<td></td>
</tr>
<tr>
<td>Buffer</td>
<td></td>
<td>-</td>
<td>-</td>
<td>Limited</td>
</tr>
<tr>
<td>Assembly</td>
<td></td>
<td>1 day</td>
<td>Low</td>
<td>Limited</td>
</tr>
</tbody>
</table>
In Table 8 the final aggregation of activities and stocking points is presented. The names of the activities and stocking points that have been aggregated or more precisely clustered are order, production and packing, transportation, arrival at port, buffer inventory, production and FGI. The rationale behind the aggregation is based upon the evaluation as explained in chapter 4 Methodology.

The first cluster of activities, order, was chosen due to the well-known lead time and the already existing organisational function borders as such. The risks identified within this part of the process can be considered to be limited and if deviations occur, they are normally solved within eight hours. The total lead time of the cluster varies from three to eight days, depending on if the order arrives just before the weekly batch closed or some days in advance. Capacity is considered unlimited due to earlier on mentioned reasons. The activities in the cluster are controlled and performed by Scania.

The second cluster of activities, production and packing, also has a well-known lead time with low deviation risk, which motivates the aggregation choice. The capacity here is also considered to be unlimited. The activities in the cluster are controlled and performed by Scania.

The third cluster of activities, transportation, normally has fixed lead times. Scania has outsourced the transportation. Shipping transportations are always subject to deviations due to e.g. bad weather conditions. Which exact way the goods are moving depends a lot on the transportation company. Scania decides and buys the transportation of a certain volume from point A to point B within a certain time limit. This also means that there is an associated capacity limitation since a specific volume is sourced. However, additional volumes can, in some cases be tolerated by the transportation company. These are the reasons why this aggregation seems appropriate.

The fourth cluster, which actually is not a cluster but one single activity, is arrival at port. This activity has been chosen to be a standalone one due to the high deviation risks associated with it. Another reason why it is treated this way is that some RPCs have temporary buffers in the harbours. The activity does not have any capacity limitations worth noting. Regarding lead time for this activity, it should be short and quite fixed, but due to the buffers in some cases as well as the high deviation risk, it varies a lot.

The fifth cluster, buffer inventory, is a standalone stocking point. It is limited in terms of capacity and has an undefined risk of deviation. The buffer level is one of the main things that are to be visualised in the simulation model and this makes it appropriate to treat the stocking point as a standalone one.

The sixth cluster, production, is a merger of assembly and body building. Not all RPCs have both activities. However, in the case where both activities exist, they are directly following upon each other in the same production line and the products always pass through the same way. Also, no stocking point between the two activities is possible. Thus, it makes sense to cluster them and only adjust the lead time of production in the model. The deviation risk of lead time is considered low and the lead time is well defined and fixed. However, an important capacity limitation prevails which can differ from one week to another and therefore it makes sense to aggregate assembly and body building this way.
The last cluster, FGI, is also a standalone stocking point. Deviation risk is undefined and no capacity limitation prevails. The main reason for the stocking point to be a standalone one though is that the FGI level is one of the most important things to be visualised in the model, just as the buffer inventory.

Table 8. Aggregated Activities and Stocking Points

<table>
<thead>
<tr>
<th>Activities and Stocking points</th>
<th>Aggregated Activity and Stocking Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order Arrival and Checking</td>
<td>Order</td>
</tr>
<tr>
<td>Order Allocation</td>
<td>Production and Packing</td>
</tr>
<tr>
<td>Order Book</td>
<td>Transportation</td>
</tr>
<tr>
<td>Batch Closed</td>
<td>Arrival at Port</td>
</tr>
<tr>
<td>Sequence Planning</td>
<td>Buffer Inventory</td>
</tr>
<tr>
<td>Batch Released</td>
<td>Production</td>
</tr>
<tr>
<td>Packing</td>
<td>FGI</td>
</tr>
<tr>
<td>Loading</td>
<td></td>
</tr>
<tr>
<td>Transportation to Harbour</td>
<td></td>
</tr>
<tr>
<td>Customs Clearance</td>
<td></td>
</tr>
<tr>
<td>Overseas Shipping</td>
<td></td>
</tr>
<tr>
<td>Customs Clearance</td>
<td></td>
</tr>
<tr>
<td>Buffer Inventory</td>
<td></td>
</tr>
<tr>
<td>Assembly</td>
<td></td>
</tr>
<tr>
<td>Body Building</td>
<td></td>
</tr>
</tbody>
</table>

6.2.2 Identification and Choice of Variables and Parameters to Include in the Simulation Model

Throughout the mapping process several parameters and variables were identified. This made it possible to list the key variable and parameter groups and the list is depicted in Table 9. The central parts in the study, namely the volumes, are considered to be variable while the other values become parameters.

Table 9. Main Variable and Parameter Groups

<table>
<thead>
<tr>
<th>Name of Group \ Type</th>
<th>Parameter</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Allocations</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Other Restrictions</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Forecast Volumes</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Order Volumes</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lead Times</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Capacity Limitations</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Buffer Inventory Levels</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>FGI Levels</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Other Volume Levels</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

By combining the groups in Table 9 with the aggregated activities and stocking points in Table 8 a long and comprehensive list of variables and parameters could be made. This list is depicted in Table 10. Each parameter and variable was given a notion determining whether it is necessary to include in the simulation model or not and if it should be included, is given a certain role in the simulation model. The judgements regarding the variables’ and parameters’ presence in the simulation model are based upon the evaluation that can be seen in Table 7. In addition, some variables and
parameters such as volume levels in each activity are necessary in order to make it possible to enter a current situation before starting to simulate.

Some variables and parameters found during the combination can be excluded due to the fact that they do not provide any value to the simulation model, e.g. if a capacity limitation can be considered indefinite it would only be an unnecessary element in the simulation model. In the table it is visible that capacity limitations are not taken into account in order, production and packing and in FGI. In the order as well as the production and packing activity, there should be no capacity limitation if the market allocation limitation is followed and in FGI a capacity limitation would affect the volume in the production activity, something that is not possible. If the production is too high in comparison to the delivered vehicles, the most likely thing to happen is that actions would be taken to decrease the production or additional storage space for the FGI would be searched for. Since the buffer inventory and the FGI are stocking points, they should not have lead times.

All parameters are treated as settings in the simulation model, while variables are categorised as status information, output or input.

<table>
<thead>
<tr>
<th>Variables and Parameters\Criteria</th>
<th>Necessary to Include in the Simulation Model</th>
<th>Role in the Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Allocations</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Forecast Volumes</td>
<td>Yes</td>
<td>Input</td>
</tr>
<tr>
<td>Order Volumes</td>
<td>Yes</td>
<td>Input</td>
</tr>
<tr>
<td>Order Lead Time</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Order Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Order Capacity Limitation</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>Production and Packing Lead Time</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Production and Packing Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Production and Packing Capacity Limitation</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>Transportation Lead Time</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Transportation Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Transportation Capacity Limitation</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Arrival at Port Lead Time</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Arrival at Port Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Arrival at Port Capacity Limitation</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Buffer Inventory Lead Time</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>Buffer Inventory Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Buffer Inventory Capacity Limitation</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Production Lead Time</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>Production Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>Production Capacity Limitation</td>
<td>Yes</td>
<td>Setting</td>
</tr>
<tr>
<td>FGI Lead Time</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>FGI Volume Level</td>
<td>Yes</td>
<td>Status and Output</td>
</tr>
<tr>
<td>FGI Capacity Limitation</td>
<td>No</td>
<td>-</td>
</tr>
</tbody>
</table>

### 6.2.3 Sources of Input

In order to make sure that it is feasible to find data to populate the simulation model with, all sources of input to the variables and parameters that were decided to be in the simulation model were listed. This can be seen in Table 11. In addition to the sources of input, complementary
characteristics such as special rules, units and notions were listed. The notions facilitate the following identification of relationships.

All lead times are necessary in order to make it possible to simulate the progression of the goods in the flow. Some activities, such as transportation, will have an important lead time. Due to this and the directive of providing a model based upon weeks, the total lead time of some activities might be split up into several parts. This means that additional notions, e.g. “transportation week 1” or “production week 2” have to be introduced. This problem is solved by adding an extra index, e.g. \( i \), signifying in which week of the aggregated activity or stocking point the products are.

\( i = [1, 2, 3 \ldots] \) (the stage of the activity)

\( t = [0:1:30] \) (the simulation model simulates at a maximum 30 weeks, \( t=0 \) is current status)

<table>
<thead>
<tr>
<th>Variables and Parameters</th>
<th>Characteristics</th>
<th>Notion</th>
<th>Unit</th>
<th>Rules</th>
<th>Source of Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Allocations</td>
<td>MA([t])</td>
<td>#/week</td>
<td>Integer</td>
<td>FAIN</td>
<td></td>
</tr>
<tr>
<td>Forecast Volumes</td>
<td>( V_{f}[t] )</td>
<td>#/week</td>
<td>Integer</td>
<td>Model level: Monthly Forecast from BU/distributor Total volumes: SWIP</td>
<td></td>
</tr>
<tr>
<td>Order Volumes</td>
<td>( V_{O}[t] )</td>
<td>#/week</td>
<td>Integer, multiple of 3</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Order Lead Time</td>
<td>LT_{O}</td>
<td>week</td>
<td>Integer</td>
<td>Order Office</td>
<td></td>
</tr>
<tr>
<td>Order Volume Level</td>
<td>VL_{O,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>KDFU</td>
<td></td>
</tr>
<tr>
<td>Production and Packing Lead Time</td>
<td>LT_{PP}</td>
<td>week</td>
<td>Integer</td>
<td>KDFU</td>
<td></td>
</tr>
<tr>
<td>Production and Packing Volume Level</td>
<td>VL_{PP,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Transportation Lead Time</td>
<td>LT_{T}</td>
<td>week</td>
<td>Integer</td>
<td>COW</td>
<td></td>
</tr>
<tr>
<td>Transportation Volume Level</td>
<td>VL_{T,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>KDFU</td>
<td></td>
</tr>
<tr>
<td>Transportation Capacity Limitation</td>
<td>CL_{T}[t]</td>
<td>#</td>
<td>Binary (1/0)</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Arrival at Port Lead Time</td>
<td>LT_{AP}</td>
<td>week</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Arrival at Port Volume Level</td>
<td>VL_{AP,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>KDFU</td>
<td></td>
</tr>
<tr>
<td>Arrival at Port Capacity Limitation</td>
<td>CL_{AP}[t]</td>
<td>Binary (1/0)</td>
<td>Pipeline Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffer Inventory Volume Level</td>
<td>VL_{BU,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Buffer Inventory Capacity Limitation</td>
<td>CL_{BI}[t]</td>
<td>Binary (1/0)</td>
<td>Pipeline Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Lead Time</td>
<td>LT_{P}</td>
<td>week</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Production Volume Level</td>
<td>VL_{P,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>Production Capacity Limitation</td>
<td>CL_{P}[t]</td>
<td>#/week</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
<tr>
<td>FGU Volume Level</td>
<td>VL_{FGU,i}[t]</td>
<td>#</td>
<td>Integer</td>
<td>Pipeline Manager</td>
<td></td>
</tr>
</tbody>
</table>

In reality, the capacity limitations are integers, more precisely specific volumes. As can be seen in Table 16 and Table 17, rounding errors occur in the simulation model if the capacity limitations are taken into account as specific volumes. In addition, the batches will be split up very early in the process and not kept together until the production at the RPC. Since the capacity limitations in transportation, arrival at port and buffer inventory seldom are activated, the authors have chosen to only assign binary values to these capacity limitations. This means that these activities or stocking points can be open (1) or closed (0). As an example, the boat can be simulated to only leave the port once every second week.
6 Prerequisites to Simulation Model Creation

6.3 IDENTIFICATION OF RELATIONSHIPS

6.3.1 Relationships between the Variables and Parameters

Below, all relationships that are required in order to create the simulation model are stated. In addition to the parameters and variables listed in Table 11 in section 6.2.3 Sources of Input, the factors in Table 12 are used. These are further explained at the end of this section.

<table>
<thead>
<tr>
<th>Additional Parameters</th>
<th>Characteristics</th>
<th>Notion</th>
<th>Unit</th>
<th>Rules</th>
<th>Source of Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lag Factor</td>
<td>LF</td>
<td>-</td>
<td>Percentage</td>
<td>User</td>
<td></td>
</tr>
<tr>
<td>Forecast Variation Factor</td>
<td>FV[t]</td>
<td>-</td>
<td>Percentage</td>
<td>User</td>
<td></td>
</tr>
</tbody>
</table>

In order to explain the relationships, an example of a simulation is stated below. This specific example is chosen since it takes into account all possible cases. The case stated in Table 13 is the basis of this explanation. In Table 13 the lead times for each activity are presented. Please note that the buffer inventory and the FGI always have a lead time of one week. The reason to this is that they are stocking points and do not have any lead times in reality but the smallest time unit that the simulation model will use is one week (due to directives).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration in Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>LT_O=2</td>
</tr>
<tr>
<td>Production and Packing</td>
<td>LT_PP=3</td>
</tr>
<tr>
<td>Transportation</td>
<td>LT_T=3</td>
</tr>
<tr>
<td>Arrival at Port</td>
<td>LT_AP=1</td>
</tr>
<tr>
<td>Buffer Inventory</td>
<td>LT_BI=1</td>
</tr>
<tr>
<td>Production</td>
<td>LT_PR=1</td>
</tr>
<tr>
<td>FGI</td>
<td>LT_FGI=1</td>
</tr>
</tbody>
</table>

Table 13. Example of Simulation and Relationships – Lead Times

Now the example can be started. In week 0 only the current status, i.e. the current volume levels of each activity and stage, are specified. This step is visualised in Table 14.
Prerequisites to Simulation Model Creation

Table 14. Example of Simulation and Relationships – Week 0

<table>
<thead>
<tr>
<th>Activity and Stage</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order 1</td>
<td>VL₀.₁[0]</td>
</tr>
<tr>
<td>Order 2</td>
<td>VL₀.₂[0]</td>
</tr>
<tr>
<td>Production and Packing 1</td>
<td>VLₚₚₚ,₁[0]</td>
</tr>
<tr>
<td>Production and Packing 2</td>
<td>VLₚₚₚ,₂[0]</td>
</tr>
<tr>
<td>Production and Packing 3</td>
<td>VLₚₚₚ,₃[0]</td>
</tr>
<tr>
<td>Transportation 1</td>
<td>VLₚ₁,₀[0]</td>
</tr>
<tr>
<td>Transportation 2</td>
<td>VLₚ₁,₀[0]</td>
</tr>
<tr>
<td>Transportation 3</td>
<td>VLₚ₃,₀[0]</td>
</tr>
<tr>
<td>Arrival at Port 1</td>
<td>VLₚ₄₅,₀[0]</td>
</tr>
<tr>
<td>Buffer Inventory 1</td>
<td>VL跚ₗ₁,₀[0]</td>
</tr>
<tr>
<td>Production 1</td>
<td>VLₚₙ₁[0]</td>
</tr>
<tr>
<td>FGI 1</td>
<td>VLₚₙ₁[0]</td>
</tr>
</tbody>
</table>

When the next week arrives, week 1, several operations take place depending on the volume levels and capacity limitations. This is depicted in Table 15 and further described in the coming paragraphs.

Table 15. Example of Simulation and Relationships – Week 1

<table>
<thead>
<tr>
<th>Activity and Stage</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order 1</td>
<td>VL₀.₁[1]=VL₀[0]</td>
</tr>
<tr>
<td>Order 2</td>
<td>VL₀.₂[1]=VL₀.₁[0]</td>
</tr>
<tr>
<td>Production and Packing 1</td>
<td>VLₚₚₚ,₁[1]=VL₀.₂[0]</td>
</tr>
<tr>
<td>Production and Packing 2</td>
<td>VLₚₚₚ,₂[1]=VLₚₚₚ,₁[0]</td>
</tr>
<tr>
<td>Production and Packing 3</td>
<td>VLₚₚₚ,₃[1]=VLₚₚₚ,₂[0]+VLₚₚₚ,₃[0]-CLₚ₁[1]*VLₚₚₚ,₃[0]</td>
</tr>
<tr>
<td>Transportation 1</td>
<td>VLₚ₁,₁[1]=CLₚ₁[1]*VLₚₚₚ,₁[0]</td>
</tr>
<tr>
<td>Transportation 2</td>
<td>VLₚ₂₃[1]=VLₚ₁,₁[0]</td>
</tr>
<tr>
<td>Transportation 3</td>
<td>VLₚ₃[1]=VLₚ₃[0]+VLₚ₃[0]-CLₚ₃₁[1]*VLₚ₃₁[0]</td>
</tr>
<tr>
<td>Arrival at Port 1</td>
<td>VLₚ₄₅₁[1]=CLₚ₄₅₁[1]*VLₚ₃₁[0]+VLₚ₄₅,₀[0]-CLₚ₃₁[1]*VLₚ₄₅,₀[0]</td>
</tr>
<tr>
<td>Buffer Inventory 1</td>
<td>VLₚ₅₁[1]=CLₚ₅₁[1]*VLₚ₄₅₁[0]+VLₚ₅₁[0]-CLₚ₅₁[1]*VLₚ₅₁[0]</td>
</tr>
<tr>
<td>Production 1</td>
<td>VLₚ₆₁[1]=CLₚ₆₁[1]</td>
</tr>
<tr>
<td>FGI 1</td>
<td>VLₚ₇₁[1]=VLₚ₇₁[0]+VLₚ₇₁[0]</td>
</tr>
<tr>
<td>FG1</td>
<td>VLₚ₈₁[1]=VLₚ₈₁[0]</td>
</tr>
</tbody>
</table>

Depending on which case that applies, a certain operation is performed. When capacity limitations are activated, i.e. when the normally outgoing volume from one activity is larger than the capacity limitation in the next activity or stocking point, this is handled in a way that stock levels increase in the first activity’s or stocking point’s last week. Only the capacity limitation can pass on to the next activity or stocking point.

In reality, the units would move throughout the pipeline in batches that are multiples of three. Batches are never separated. However, taking this into account would increase the complexity of the simulation tremendously and consequently a delimitation has been made regarding this.
6 Prerequisites to Simulation Model Creation

In Table 15, week 1 and its operations are shown. Below, a walk-through of some of the steps in this process is presented.

To start with, the order volume in week 0, \( V_{O[0]} \), arrives. Since no capacity limitation exists in order 2, the current status, i.e. the volume level in order 1 in week 0, \( VL_{O,1}[0] \), leaves. This results in \( VL_{O,1}[1] \).

The second step is to introduce the volume that left order 1, \( VL_{O,1}[0] \), into order 2. This volume, plus the order 2 volume in week 0, \( VL_{O,2}[0] \), minus the volume that can leave order 2, will be the new order 2 volume, \( VL_{O,2}[1] \).

For the steps in production and packing 1-3 and transportation 1-3 the above mentioned patterns are applicable. In Table 15 it can be seen that some of these stages are subject to capacity limitations.

In arrival at port 1, the volume that arrives is the volume that could enter from the previous activity due to capacity limitations in arrival at port 1, \( CL_{AP}[1]*VL_{T,3}[0] \). As in the previous steps, the volume in arrival at port in week 0, \( VL_{AP,1}[0] \), is present. What leaves the arrival at port 1 is the volume that is allowed to leave due to capacity limitations in the buffer inventory 1, \( CL_{BI}[1]*VL_{AP,1}[0] \). The volume that arrived, plus the present volume minus the volume that leaves results in \( VL_{AP,1}[1] \).

Since the capacity limitations in the transportation, arrival at port and buffer inventory are binary (1 or 0), either everything pass or nothing pass through these activities. However, in production at the RPC, the capacity limitation vary, which affects the buffer inventory as well as the FGI. In this case, a problem occurs. Since the capacity limitations signify the total volume of units that can pass through one activity during a week and the simulation model handles several different vehicle models, one important question arises. Which models should pass, and thus be allowed to enter the next activity, and which ones should stay? The solution that has been chosen for the capacity limitation in the production is to compute the split between different models in the forecast. This operation is depicted in Table 16. In the Table 16 case, the volumes in the activity before the capacity limitation are greater than the forecast and thus the volumes that will pass to the next activity can be fulfilled. However, in the Table 17 case, model B does not have a sufficient volume in the first activity and thus it would be inappropriate to give this model as many slots in the production as the forecast normally would give. This is why an adjusted forecast volume is computed, which will prevent that slots in the production will be allocated to models that do not exist in the buffer inventory.

What also can be seen in Table 16 and Table 17 is that one model less than the capacity limitation will be produced (seven instead of eight). This is due to the fact that only complete units can be produced and thus numbers have to be rounded. This error will prevail and further examples can be found in Appendix VIII. Sensitivity Analysis.
Table 16. Capacity Limitation in Production – Case 1

<table>
<thead>
<tr>
<th>Models</th>
<th>Volume in activity A</th>
<th>Forecasted Volumes</th>
<th>Forecasted Shares</th>
<th>Capacity Limitation in activity B</th>
<th>Volumes that pass to Activity B</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>2/13=15 %</td>
<td>8</td>
<td>15 %*8=1</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>3</td>
<td>3/13=23 %</td>
<td></td>
<td>23 %*8=2</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>4</td>
<td>4/13=31 %</td>
<td></td>
<td>31 %*8=2</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>4</td>
<td>4/13=31 %</td>
<td></td>
<td>31 %*8=2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16</td>
<td>13</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

Table 17. Capacity Limitation in Production – Case 2

<table>
<thead>
<tr>
<th>Models</th>
<th>Volume in activity A</th>
<th>Forecasted Volumes</th>
<th>Adjusted Forecasted Volumes</th>
<th>Adjusted Forecasted Shares</th>
<th>Capacity Limitation in activity B</th>
<th>Volumes that pass to Activity B</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2/14=14 %</td>
<td></td>
<td>14 %*8=1</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>14</td>
<td>4</td>
<td>4/14=29 %</td>
<td></td>
<td>29 %*8=2</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4/14=29 %</td>
<td></td>
<td>29 %*8=2</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4/14=29 %</td>
<td></td>
<td>29 %*8=2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16</td>
<td>20</td>
<td>14</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

These computations lead to the need of an additional notion, \( CL_{P,X} \), which signifies the capacity limitation for model \( X \). \( CL_{P,X} \) is always an integer. For example, in Table 17, the figures can be found in the very right column and thus \( CL_{P,A} = 1 \) and \( CL_{P,B} = 2 \).

The method described above is used in the buffer inventory 1 computations in Table 17 and defines the value of the capacity limitation in production 1, \( CL_{P}[1] \). Please note that the \( CL \) notion differs from the rest of the \( CL \)-notions since it signifies a model specific capacity limitation and not a total capacity limitation in the operations stated. Thus, depending on whether the capacity limitation is larger or smaller than the volume in buffer inventory 1 in week 0, \( VL_{BI,3}[0] \), the volume level in buffer inventory 1 in week 1, \( VL_{BI,3}[1] \), will have two possible outputs. However, apart from the calculation of the capacity limitation, the computations are similar to the ones made in the previous steps.

In production 1, the computations are also the same, but the capacity limitation for each model is computed according to the method described above.

For the last stocking point, FGI, additional adjustments take place due to the users’ simulation wishes. To begin with, a lag factor can be applied and secondly, a variation to the forecast can be applied. In week 1, only the second factor can be seen due to logical reasons, but in week 2, both are applicable. In Table 15, this can be seen as forecast variation in week 1, \( FV[1] \). The variation in forecast works in a way that it changes the volume level that is taken out from the FGI. For example, if the forecast variation for week \( X \) is 20 %, the requested volumes of all models will increase by 20 % and thus more units than expected will be taken from the FGI. On the contrary, if the forecast variation for week \( X \) is -20 %, the requested volume would drop with 20 % and the FGI volume level would be higher than expected.

The operations taking place in week 2 are depicted in Table 18. These operations are in general the same as for week 1 in Table 15, but the lag factor is visible. The lag factor has been introduced in order to simulate what will happen with the demand if it cannot be fulfilled the exact week. For example, if four trucks of model A are requested in week \( X \), but only two trucks of the model are available in week \( X \), the demand can be pushed forward to week \( X+1 \). This means that if the...
forecasted requested volume in week X+1 is seven, then two units will be added to that, which gives nine, due to the fact that they were not delivered the week before. However in reality, some selling opportunities may be lost if delivery at the right time is not possible. Therefore, a lag factor is introduced. If the lag factor is 100 %, then all demand is pushed forward from one week to the next if not fulfilled. If the lag factor is set to 0 %, the demand will disappear completely if the units cannot be delivered in the right week. A value of 50 % pushes half of the non-fulfilled demand volume over to the next week etcetera.

Table 18. Example of Simulation and Relationships – Week 2

<table>
<thead>
<tr>
<th>Activity and Stage</th>
<th>Operation</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order 1</td>
<td>VL_{O,1}[2]=V_{O,1}</td>
<td></td>
</tr>
<tr>
<td>Order 2</td>
<td>VL_{O,2}[2]=VL_{O,1}[1]</td>
<td></td>
</tr>
<tr>
<td>Production and Packing 1</td>
<td>VL_{PP,1}[2]=VL_{O,2}[1]</td>
<td></td>
</tr>
<tr>
<td>Production and Packing 2</td>
<td>VL_{PP,2}[2]=VL_{PP,1}[1]</td>
<td></td>
</tr>
<tr>
<td>Production and Packing 3</td>
<td>VL_{PP,3}[2]=VL_{PP,2}[1]+VL_{PP,3}[1]-CL_{T,2}[2]*VL_{PP,3}[1]</td>
<td></td>
</tr>
<tr>
<td>Transportation 1</td>
<td>VL_{T,1}[2]=CL_{T,2}[2]*VL_{PP,3}[1]</td>
<td></td>
</tr>
<tr>
<td>Transportation 2</td>
<td>VL_{T,2}[2]=VL_{T,1}[1]</td>
<td></td>
</tr>
<tr>
<td>Transportation 3</td>
<td>VL_{T,3}[2]=VL_{T,2}[1]+VL_{T,3}[1]-CL_{AP}[2]*VL_{T,3}[1]</td>
<td></td>
</tr>
<tr>
<td>Arrival at Port 1</td>
<td>VL_{AP,1}[2]=CL_{AP}[2]*VL_{AP,1}[1]+VL_{AP,1}[1]-CL_{B}[2]*VL_{AP,1}[1]</td>
<td>VL_{AP,1}[2]&lt;VL_{B,1}[1]</td>
</tr>
<tr>
<td>Buffer Inventory 1</td>
<td>VL_{B,1}[2]=CL_{B}[2]*VL_{AP,1}[1]+VL_{B,1}[1]-CL_{P}[2]</td>
<td>CL_{L}[2]&gt;=VL_{B,1}[1]</td>
</tr>
<tr>
<td>Production 1</td>
<td>VL_{P,1}[2]=CL_{P}[1]</td>
<td></td>
</tr>
<tr>
<td>FGI 1</td>
<td>VL_{FG,1}[2]=VL_{P,1}[1]+VL_{FG,1}[1]-(FV[2]+1)*V_{f}[2]</td>
<td>0&lt;=VL_{FG,1}[2]&lt;VL_{B,1}[1]+VL_{FG,1}[1]</td>
</tr>
<tr>
<td></td>
<td>VL_{FG,1}[2]=0</td>
<td>0&lt;=VL_{FG,1}[2]&lt;VL_{B,1}[1]+VL_{FG,1}[1]</td>
</tr>
<tr>
<td></td>
<td>VL_{FG,1}[2]=VL_{FG,1}[1]+VL_{FG,1}[1]-CL_{F}[1]<em>FV[2]</em>(FV[1]+1)*V_{f}[1] -VL_{FG,1}[1]+VL_{FG,1}[1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0&lt;=VL_{FG,1}[2]&lt;VL_{B,1}[1]+VL_{FG,1}[1]</td>
</tr>
</tbody>
</table>

Week 3 would follow the same pattern as for week 2 and this will repeat itself until week 30, which is the length limit of the simulation.
7 Development and Validation of the Simulation Model

In this chapter the findings regarding user-friendliness and robustness are first presented. Then, the creation process of the simulation model is described and finally the testing of the simulation model in order to ensure its accuracy and validity is explained.
7 Development and Validation of the Simulation Model

7.1 Development

7.1.1 User-Friendliness and Robustness

It is important to ensure that a simulation model, at least when thinking of a logistic such, is not only performing the right operations and rendering the correct result, but that it also increases the comprehension of the entire flow and the relationships between parts of it. Sometimes it is useful to demonstrate flows with images and symbols and not only numbers. What is also of value is to separate different types of data and operations. For example, a common way of using Microsoft Excel sheets is to have one with basic input data that is rarely modified, one in which the values that are to be simulated are entered, one where results can be seen (often visually with graphs or figures) and one where all computations are made. (Abrahamsson, 2013)

Primarily, the users should be put in focus and their needs should be clearly specified. If the usage of a simulation model should be stimulated, the first thing to make sure is that the resulting views it gives are showing what the user needs to know. In order to reduce the resistance of using a model and facilitate as much as possible for the user, the number of steps that a user has to do should be as limited as possible. For example, having to switch between different tabs and sections, scrolling and searching within sheets should be avoided in all cases possible. One additional click can be very annoying. Regarding simulation models it is practical for a user to easily be able to see the effect of a changed input on the results. The best thing would probably be to show the results in the same view as the input and thus the user does not have to remember the previous results in order to compare them to the new ones. (Stahre, 2013)

Regarding robustness, it is quite difficult to build really robust Microsoft Excel simulation models. Also, creating a simulation model only with Microsoft Excel formulas can be quite difficult to do in an understandable way. It is easier to present Visual Basic code in a clear way. By using as much data validation as possible and preventing invalid inputs by warnings our conditional formatting, many errors can be avoided. Another important thing is to lock appropriate parts of the simulation model, and maybe also have different user types with different access in order to only make the simulation model more customised in terms of modifiability. (Stahre, 2013)

7.1.2 Creation

As explained in section 4.2.5 Data Collection and Analysis and Execution, the creation of the simulation model was an iterative process. Below, the structure and the content of the simulation model are described and the reasoning behind these elements is presented.

Structure

To start with, a structure of the simulation model was developed. This structure was based upon the discussions held regarding user-friendliness and robustness as well as the objective with the simulation model. In this case Microsoft Excel has been used and thus a certain adaption to this software had to be made. The order of the elements has been chosen so that the user will fill out the forms in a logical order, i.e. the user should start by reading the user manual and the final thing is to look at the results.

In Table 19, a summary of the structure of the simulation model is presented. All tabs are listed in the table and it is specified in it whether the user and the administrator can see it and/or modify it.
Table 19. Summary of the Simulation Model Structure

<table>
<thead>
<tr>
<th>Tab</th>
<th>Seen by the User</th>
<th>Data can be Entered by the User</th>
<th>Seen by the Administrator</th>
<th>Can be Modified by the Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Manual</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Administrator Manual</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lists</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lists 2</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Settings</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Forecasts</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Statuses</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Simulation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Results</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computations 1</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computations 2</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computations 3</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computations 4</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Below, the reasoning behind each tab is presented.

An important part of the simulation model is a manual in which the users can find out how the simulation model is to be used, which operations that can be made within it and what limitations the simulation model has. This information should be easy to find and it differs a lot from the rest of the simulation model in terms of content; therefore it was assigned an own tab named User Manual. Also, a separate manual has been created for the administrator. In this tab, named Administrator Manual, deeper explanations to the computations can be found.

In order to allow the user to insert only suggested values and values that the simulation model can handle, lists are created in separate sheets that are used in the settings and input sheets as choices. The tab Lists is the tab that the user will have to keep up to date while the tab Lists 2 is designed to be updated by the administrator. The lists are essential to the functioning of the simulations.

Next, when a user is to carry out a simulation, input data has to be provided so that the simulation model gets all the information needed. Basic settings such as lead times, capacity limitations, market allocation and targets are included in a tab named Settings. The forecast is another important input, which only will be updated once every month, thus it has been given an own tab named Forecast. In addition to this, the current pipeline volumes are of great importance in order to create a current status that the simulation model can start with and these statuses have been placed in the tab Statuses.

The aim of the simulation model is to simulate different order volumes, these numbers are therefore clustered together with simulation specific input such as lag and variation in forecast. When these values have been entered and the settings are done, a simulation can be launched by the user. Then the user can continue fine-tuning the order volumes by analysing different charts in the same view. Since the simulation part is where the user will spend the majority of the time, it has also been placed in a separate tab named Simulation.

All results of the simulation launched by the user are presented in different charts in a separate sheet named Results. However, the user can, as explained above, see two charts of own choice in the
7 Development and Validation of the Simulation Model

Simulation tab. This way it gets easier to test many different combinations of order volumes and the user does not have to jump between different tabs.

The simulation itself consists of several computations. A variety of rules apply for how the goods can move in the pipeline and these are the main part of the computation. The output from the computation is then extracted and inserted into tables that are structured in a way that facilitates the creation of charts. All these data and computations should not be something that the users should modify. In order to separate the different computations types, these are placed in four different Computations tabs.

In order to categorise and be clear about the different content, e.g. input, output and computations in the simulation model, colour coding was used to mark the different areas. The resulting structure, as the user sees it, can be seen in Figure 50, and the administrator’s view can be seen in Figure 51.

![Figure 50. Microsoft Excel Sheet Structure for the Simulation Model – User View](image1)

![Figure 51. Microsoft Excel Sheet Structure for the Simulation Model – Administrator View](image2)

Content

User Manual

The user manual contains descriptions of the different parts of the simulation model as well as user directives. To begin with, an introduction is presented. In this, a visualisation of the pipeline is depicted, colour coding is explained and general recommendations are given. This can be seen in Figure 52.
After the introduction each tab is described. All main input fields are numbered and the user can read about what actions that should be taken and what to think about in the section. This is written as “To Do” and “To Note”. An example showing the user directives for the tabs Lists and Settings is depicted in Figure 53.
In order to facilitate the comprehension of the functioning of the simulation model, such as which numbers the charts actually are based upon and what kind of errors that might occur, explanatory figures have been inserted in the user manual. An example of this can be seen in Figure 54 and this specific example describes the difference between the charts on model level and the aggregated charts where only the total volume level is shown.
Administrator Manual

An additional manual for the administrator has been inserted in the model. The administrator has the same structure as the user manual but it contains explanations of the tabs that normally are hidden for the user. For example, computations and actual operations performed within the simulation model are described. In order to increase the understanding of the Microsoft Excel code (which easily can get complicated and blurry), decision trees and figures have been provided. An example of this is depicted in Figure 55 and the corresponding Microsoft Excel formula is the following:

```
=IF(SK161=0;"";IF(ISNUMBER(Settings!SCS48)="1";IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1)<N41;IF(ISERROR(VLOOKUP(SK161;Simulation!SCS40:SCS3760;MATCH(Comp_1!S161;Simulation!SCS36:SCS3760;0));0);N41-IFERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);IF(ISERROR(VLOOKUP(SK161;Simulation!SCS40:SCS3760;MATCH(Comp_1!S161;Simulation!SCS36:SCS3760;0));0);N41+1);N41+IF(ISNUMBER(Settings!SCS48)="1";IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1)<N41;IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1);N41+IF(ISNUMBER(Settings!SCS48)="1";IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1)<N41;IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1);N41+IF(ISNUMBER(Settings!SCS48)="1";IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1)<N41;IF(ISERROR(LOOKUP(OS40;SCS40:SCS3760;MATCH(S161;SCS40;SCS3760;0));0);N41+1)))))
```
Figure 55 shows how the decision regarding which volume that should be shown in the specific cell is made.

Lists
In the Lists tab, which is depicted in Figure 56, all lists that the user needs to update and maintain are presented. The tab includes lists such as models and names.
Lists 2
In the Lists 2 tab, presented in Figure 57, lists that are necessary in order to carry out the simulation computations can be found. For example possible values that show up in drop down menus and that are not RPC specific can be found here. These lists are not meant to be modified by the user and due to this the tab will be hidden in the simulation model.

<table>
<thead>
<tr>
<th>Refill</th>
<th>Capacity Limitation</th>
<th>Forecast Variation</th>
<th>Non-Satisfied Demand</th>
<th>netChart</th>
<th>PartPeriod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refill Truck</td>
<td>-</td>
<td>-50%</td>
<td>0%</td>
<td>Buffer Inventory: Production and FGI</td>
<td>01.1</td>
</tr>
<tr>
<td>Refill Bus</td>
<td>0</td>
<td>-40%</td>
<td>10%</td>
<td>Total Buffer Inventory: Production and FGI</td>
<td>01.2</td>
</tr>
<tr>
<td>Non_Refill Truck</td>
<td>-30%</td>
<td>20%</td>
<td></td>
<td>FGI</td>
<td>01.3</td>
</tr>
<tr>
<td>Non_Refill Bus</td>
<td>-20%</td>
<td>30%</td>
<td></td>
<td>Total FGI</td>
<td>01.4</td>
</tr>
<tr>
<td></td>
<td>-10%</td>
<td>40%</td>
<td></td>
<td>Buffer Inventory</td>
<td>02.1</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>50%</td>
<td></td>
<td>Total Buffer Inventory</td>
<td>02.2</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>60%</td>
<td></td>
<td>Pipeline Week 1</td>
<td>02.3</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>70%</td>
<td></td>
<td>Total Pipeline Week 1</td>
<td>02.4</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>80%</td>
<td></td>
<td>Pipeline Week 2</td>
<td>03.1</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>90%</td>
<td></td>
<td>Total Pipeline Week 2</td>
<td>03.2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>100%</td>
<td></td>
<td>Pipeline Week 3</td>
<td>03.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total Pipeline Week 3</td>
<td>03.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pipeline Week 4</td>
<td>04.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total Pipeline Week 4</td>
<td>04.2</td>
</tr>
</tbody>
</table>

Figure 57. Simulation Model Tab: Lists 2

Settings
In the Settings tab depicted in Figure 58, the lead times of different activities for the specific RPCs are entered. For the buffer inventory as well as the FGI, the lead times are fixed to 1 week, since these actually are stocking points and not activities and the smallest units that can be used in the model is one week. In addition to lead times, capacity limitations are entered. Drop-down menus ensure that only zero or infinity can be entered in transportation, arrival at port and buffer inventory. In production, integers greater than (or equal to) zero are allowed to be entered. No limitations can be entered in order, production and packing and FGI. Also, market allocations for each week are entered in the Settings tab as well as targets regarding volume levels in the buffer inventory and FGI. An upper limit can also be inserted in the buffer inventory and the FGI. Market allocation, targets and limits can take any value as long as it is a positive integer.
Forecast

In the Forecast tab, which is shown in Figure 59, the user enters the most recent forecast from the BU/distributor that covers the coming 12 months. The forecasted volumes for each model and month are entered. For example, in Figure 59, the forecast says that 20 units of the refill truck Model B are predicted to be delivered in May 2013. The user enters the type and model by means of drop-down menus. Depending on which type that is selected, the appropriate models become available to choose. The total column sums up the total forecast over the year.

Figure 59. Simulation Model Tab: Forecast
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Statuses

In the Statuses tab depicted in Figure 60, the user enters the current volume level of each model in each activity. For example, in Figure 60, there are currently five units of the refill truck Model A in order 1. The user enters the type and model by means of drop-down menus. Depending on which type that is selected, the appropriate models become available to choose.

![Figure 60. Simulation Model Tab: Statuses](image)

Simulation

In Figure 61 an extract from the Simulation tab is shown. The major thing that is entered here is the order volumes for each model that the user wants to simulate. For example, six units of the refill truck Model A are ordered in week 1. The market allocation is only used as an input criterion, which means that it is not included in any computations but an orange warning appears if the user surpasses this level when entering orders. The same is valid for the criteria that order volumes should be multiples of three; a red warning appears if the user tries to enter anything else. However, sometimes the user actually has to order a volume that is not a multiple of three or that surpasses the market allocation. This is why it is still possible to simulate the values, even though they are not the most convenient ones. The user enters the type and model by means of drop-down menus. Depending on which type that is selected, the appropriate models become available to choose.

In the Simulation tab the user also enters a specification of which weeks’ snapshots of the pipeline that should be seen in the results. Four charts of snapshots can be shown at once. For example, in Figure 61, the snapshots are chosen to depict the pipeline in week one, two, three and four. Also, the lag factor and the forecast variation are entered in the simulation tab. The lag factor stretches from 0-100 %. The forecast variations can be chosen from a drop-down menus and ranges from -50 % to +50 % in steps of 10 percentage points. This is also visible in Figure 61.

In order to make the simulation model user friendly and prevent the user from having to switch between different sheets, two charts can be seen in the Simulation tab. Both charts can be selected from dropdown lists, which represent all charts available in the Results tab, and thus the user can customise its view when running the simulations.
When the user has entered everything the simulation button is pushed in order to generate the simulation results. The button can be seen in Figure 61 as well.

![Simulation Model Tab: Simulation](image)

**Figure 61. Simulation Model Tab: Simulation**

**Results**

In the Results tab depicted in Figure 62, several charts are presented. The charts are made in a dynamic way so they update themselves automatically when the user pushes the simulation button. In total, 14 charts are shown. Seven of them are showing numbers on a model level and the other seven show totals. In order to facilitate the analysis and present the numbers in a more visible way to the user, all non-refill vehicles have been clustered and presented together as if they were only one single model. Another reason is that the non-refill units should not be inventory controlled.

First, two charts depicting the volume levels in the buffer inventory, production and FGI all together are presented. The first of these two shows the volume levels for each model and the second one shows the total volume. The total volume is more exact than the per model volume since it is not affected by the rounding error that occurs when a split according to the forecast is done, in order to take into account the capacity limitation in the production on a model level. Second, two charts showing the FGI volume levels are presented. Finally, two charts showing the buffer inventory levels are presented. The characteristics of these buffer inventory and FGI charts are the same as for the first presented charts. All these charts can be seen in Figure 62.
Finally, eight charts presenting snapshots of the pipeline at four different moments are presented. As for the FGI and buffer inventory charts, charts on a model level are shown to the left and totals to the right. An example of a snapshot for week 2 can be seen in Figure 63.
Development and Validation of the Simulation Model

The charts are based upon weekly values of the volume levels in different activities. It is important to be aware about which data that the charts are based upon. An example of plotted data can be seen in Table 20, where the status is zero in every activity to start with and then ordered volumes start to arrive in the buffer inventory in week X. The volumes then move forward each week. However, in the FGI, the plotted volume will not be 10 or 12 since the demand is 15 and thus 10 and 12 units will be taken out. This leads to a plotted value of 0. Therefore, the chart that represents the buffer inventory will alternate between 10 and 12 units from the week when the ordered volumes arrive and forward while the FGI chart will show a volume level of zero constantly. The circumscribed cells in Table 20 represent the plotted values.

Table 20. Example of Underlying Data Points to Charts in the Results Tab

<table>
<thead>
<tr>
<th>Week</th>
<th>Buffer Inventory</th>
<th>Production</th>
<th>FGI</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week X</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Week X+1</td>
<td>12</td>
<td>10</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Week X+2</td>
<td>10</td>
<td>12</td>
<td>10-10=0</td>
<td>15</td>
</tr>
<tr>
<td>Week X+3</td>
<td>12</td>
<td>10</td>
<td>12-12=0</td>
<td>15</td>
</tr>
<tr>
<td>Week X+4</td>
<td>10</td>
<td>12</td>
<td>10-10=0</td>
<td>15</td>
</tr>
</tbody>
</table>

A chart that corresponds to the buffer inventory values in Table 20 can be seen in Figure 64. In the figure, it is also possible to see that the volume levels in the buffer inventory do not lie between 10 and 12 units in reality. In fact, in this example the volume level in the buffer inventory will decrease to zero between these points.

Figure 64. Plot of Buffer Inventory Volume Levels in Table 20

Computations 1

The main computation operations are described in section 6.3.1 Relationships between the Variables and Parameters. The tab Computations 1 is shown in Figure 65. In Computations 1, basically all major computations are carried out, thus it is here where all volumes move from one week to another with respect to the relationships defined. The tab probably contains the heaviest computations in the simulation model. The sheet contains 31 blocks and each block represents a week. Week 0 only
contains the current status and from week 1 and forward the simulation starts. In Figure 65 week 0 is visible and, as can be seen, no capacity limitations are active here.

In Figure 66, which shows week 1, capacity limitations in production are visible. The numbers to the right represent the volume levels of each model in each activity. No user is to modify this tab and consequently it is hidden.

In the Computations 2 tab, which is shown in both Figure 67 and Figure 68, the ground for capacity limitations on model level is calculated. The splits described in Table 16 and Table 17 in section 6.3.1 Relationships between the Variables and Parameters are computed in this tab.

In Figure 67, the first part of the computations is made. It compares demand (lag included) with the buffer inventory level. This is done in order to ensure that if there is a lack in the buffer inventory; slots in the production will not be unused. Instead, the lowest value is returned and a new split that only takes into account the available units in the buffer inventory is computed the table in Figure 68.

In Figure 68 the splits that are input to the capacity limitations in tab Computations 1 are shown. No user is to modify this tab and consequently it is hidden.
Development and Validation of the Simulation Model

Figure 68. Simulation Model Tab: Computations 2 – Part 2

**Computations 3**
The tab Computations 3 extracts figures from the tab Computation 1 and presents the data in a way that it is suitable for making charts. An example is presented in Figure 69, where the data that is underlying in the buffer inventory chart in the Results tab is gathered. No user is to modify this tab and consequently it is hidden.

Figure 69. Simulation Model Tab: Computations 3

**Computations 4**
The tab named Computations 4 can be seen in Figure 70. In this tab the different types of trucks and buses are summed for each week. The computations are very simple. These numbers are used in the tab Computations 3 and thus they are needed in order to create the graphs. No user is to modify this tab and consequently it is hidden.

Figure 70. Simulation Model Tab: Computations 4
7.1.3 Input Error Prevention
In order to prevent the users from entering invalid data in the simulation model, several types of error prevention were introduced. Conditional formatting, warnings and data validations were implemented where the creators believed that it was necessary. Example of the error prevention can be seen in Figure 56 where a warning appears.

7.2 VALIDATION
Even though the simulation model has been validated continuously during the development, it is of relevance to conduct final tests that can confirm the validity and ensure that no major bugs or problems exist in it. First, the simulation model was tested by a test user who will use the simulation model once it is finished. This strengthened the credibility of the simulation model and increased the validity. Second, the authors ran a sensitivity analysis. This tested the simulation model’s validity. Finally, the simulation model was tested with real case data, something that also confirms the validity and increases the credibility.

The simulation model can only be internally validated (notion stated by Rehman and Pedersen (2012)) since it has not been possible for the researchers to access complete historical real case data due to the fact that non-satisfied demand has not been registered. Furthermore, no output analysis is needed since the simulation model does not contain any random samples from probability distributions (according to the reasoning by Law (2007)).

7.2.1 Test Users
Annmari Balázs was tester of the simulation model. By discussing the remarks and the problems encountered, the authors and the tester tried to find out what could be done in order to ameliorate the simulation model and modifications to it were made. The remarks the tester had are listed below together with their solutions.

- “Assume that it is vacation and the production and packing are closed. Then, what normally happens is that the orders are forwarded to production weeks lying after the vacation. However, the simulation model does not seem to handle this case in that way.”
  - This problem was solved by locking production and packing and instead using market allocation as a limitation when it is vacation times. An example of the solution is depicted in Figure 76.
- “It is difficult to recognise which week I am in when using the simulation model. We always use the part-period language and in this model everything is noted week 1-week 30.”
  - The view where it turned out to be important to see part periods instead of the ordinary week 1-week 30 was in the market allocation field, since it was here vacation weeks could be entered. As a result, the market allocation time scale was changed.
- “Sometimes all we want to see is what can be found at the RPC, i.e. what is in the buffer inventory, the production and the FGI. A chart showing all of these would be great to have”
  - Consequently, two new graphs were introduced. Both showed the buffer inventory, Production and FGI together. However, of the charts depicted the total volumes and the other showed volumes on model level.
7 Development and Validation of the Simulation Model

7.2.2 Sensitivity Analysis
An extensive sensitivity analysis of the simulation model has been made. It included three parts. The first part was a tested the basic functionality of the simulation model and comprised among others analysis of different order, forecast and status volumes. The second part focused on testing the capacity limitations, the forecast variations and the lag factor. The third part tested how the simulation handled extreme values.

The sensitivity analysis is quite vast and heavy to go through but in order to fully understand the reasoning behind the simulation model it is highly recommended to read Appendix VIII. Sensitivity Analysis where the complete sensitivity analysis is presented. The simulation model worked in accordance with the predictions in the sensitivity analysis, apart from a minor computation error that was discovered and fixed immediately. Some weaknesses in the computations, which were discovered already during the creation phase and that are inevitable, were confirmed in the sensitivity analysis. To conclude, the authors are satisfied with the simulation model’s performance when it comes to the tests that were made during the sensitivity analysis.

7.2.3 Real Case: Malaysia
Malaysia has been chosen to be a real case test due to several reasons. First, the authors have not had contact with this RPC during the study, which renders the Malaysia case a good test for investigating the wanted generalisability of the simulation model. Second, the RPC has all four types of units (refill truck, refill bus, non-refill truck and non-refill bus) and mixed sizes of the volumes. This will among others show whether the charts are clear and understandable. Thirdly the forecasted volumes fluctuates a lot, which will probably activate the capacity limitations and make it easy to follow changes in the pipeline. The lead times that are valid for Malaysia are presented in Table 21.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Weeks</th>
<th>Aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Production and Packing</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Transportation</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Arrival at Port</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Buffer Inventory</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Production</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>FGI</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

In Table 22 the settings for the Malaysia case are presented. The lag is assumed to be 50% for the Malaysian market and the authors have chosen not to apply any forecast variations initially.

<table>
<thead>
<tr>
<th>Capacity Limitation Transportation</th>
<th>Capacity Limitation Arrival at Port</th>
<th>Capacity Limitation Buffer Inventory</th>
<th>Capacity Limitation Production</th>
<th>Lag</th>
<th>Forecast Variation</th>
<th>Market Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>∞</td>
<td>∞</td>
<td>15</td>
<td>0%</td>
<td>0%</td>
<td>30</td>
</tr>
</tbody>
</table>

The most recent forecast is shown in Figure 71. As can be seen, the values varies a lot.
The current pipeline status in the Malaysia pipeline is presented in Figure 72. What is visible here is that quite few volumes of quite few models are on their way to Malaysia and the main volumes can be found in the buffer inventory.

When the authors inspected the charts with the results (before any orders had been placed) an error was found. The simulation model returned incorrect values in one specific case where forecasted volumes existed but only for models that were not available in the buffer inventory. In the computations this lead to all units in the buffer inventory (the not forecasted ones) were produced. The error was easy to fix and since this was a very unusual case, the authors judged that the sensitivity analysis made previously did not need to be redone.
At the beginning, before any orders have been placed, the volume levels in the buffer inventory and the FGI are as shown in Figure 73 and Figure 74. These results originate from the corrected version of the simulation model.

Now, this real case test aims for striving after well-balanced volume levels in the buffer inventory and FGI. The authors tested different order volumes and set market allocation to zero in the weeks 4 and 5, which corresponds to a fictive vacation in the weeks 8 and 9 in production. This means that no goods should arrive in the buffer inventory in the weeks 16 and 17. The order volumes that have been chosen and the vacation weeks with no orders can be seen in Figure 75.
Below in Figure 76 and Figure 77 the results regarding buffer inventory and FGI are presented. In the buffer inventory it is clear that nothing arrives in the weeks 16 and 17. The increasing volume levels of non-refill trucks (around 30 units in week 14-week 23) originate from a planned ramp up in order to meet a high demand. What also can be established is that when the non-refill truck production increases a lot, the production volumes of the other models decrease and their levels in the FGI are reduced. Normally, non-refill trucks and non-refill buses should not be part of the inventory control since they should have a final customer from the very beginning.
In order to test how robust the chosen order solution was, a forecast variation factor of ±40% was entered. The results of this can be seen in Figure 78 and Figure 79. To conclude, the volume levels are a little bit affected by the variation in the forecast, which is normal, but the chosen order solution still seems to be acceptable since no major volumes are lacking in the FGI.
To conclude, some minor errors were found during the test with real data from Malaysia. However, the authors consider that the simulation model works well after the correction of the errors. The charts are clear and it is easy to distinguish the different models.
8 JUSTIFICATION AND DELIVERY

In this chapter a description of the simulation model is given and the advantages and the drawbacks of the simulation model are explored and explained. In order to strengthen the reasoning behind the explanations, examples are provided.
8 Justification and Delivery

8.1 Description
According to Taylor’s (1997) case analysis framework’s fourth step (which is included in this study’s analysis model), the solution that has been chosen should be described.

The descriptive part of the simulation model comprises explanations of how the simulation model works, how to use it and how well it works in different cases. All this information is presented in the sections 7.1 Development, 7.2 Validation and 8.2 Justification. Furthermore, a user manual with detailed directives of how to use the simulation model is provided in the simulation model itself.

8.2 Justification
To ensure a correct usage of the simulation model and the results it provides, it is of importance to be clear about its advantages and drawbacks. In the sections below, these areas are explored.

8.2.1 Advantages

Visibility
The greatest advantage is the highly increased visibility of the volumes in the pipeline, the buffer inventory and the FGI. The different charts showing volumes both on model level and total level clearly depicts the future statuses. In addition, the users can set targets and limits that are visible in the charts and that will be helpful when trying to find out the best order volumes. Hopefully, the visualisation of what happens in the pipeline will increase the users’ understanding for how the system works.

Decision Making
The simulation model facilitates the decision making of order volumes a lot for the user. The possibility to quickly try new input values and directly get a visual chart of the output solution, a simulation characteristic named accelerated time by Lumsden (2012), makes it easy to adjust the order volumes and find the most appropriate. The scenario handling, e.g. the possibility to close certain activities such as transportation or introducing vacation at a production site during some weeks, is also a useful tool for the pipeline managers. As an example, it becomes clear that if the boats only leave every second week, the mean stock levels increase a lot.

Market Adaptation
The simulation model also has several functions that permit to customise the simulation and adapt it to local market conditions. Examples of this are the lag factor and the forecast variation factor. Lag, which relates to how much of the demand that is forwarded to the next week if the demand cannot be fulfilled, is something that is market specific.

8.2.2 Drawbacks

Batches
One of the main drawbacks is the fact that the model cannot handle batches in the production at the RPC. In the beginning of the pipeline, arrival at port included, the goods move forward in batches. But due to the capacity limitation in the production at the RPC and the operations that are activated when this occurs, batches are being split up in the simulation model even though this never happens in reality. More about why this is necessary can be found in section 6.3.1 Relationships between the Variables and Parameters. However, it is highly improbable that the user can predict exactly which batches that are to be produced since this normally is decided short time in advance at the RPC.
Granularity
The granularity is quite rough in the simulation model since it only handles weeks and not days. The granularity was a directive from the taskmaster. However, it might be unnecessary to use a higher granularity than weeks since the lead times are very long and a re-planning point is present at the RPC. The simulation model will never be exact but it will give a good hint about the statuses of the different volumes and it will be clear to the user if stocks are decreasing or increasing.

Charts
When the users are to analyse the results presented in the charts, it is of high importance that they understand how the charts have been created. An example of a case that can be misunderstood is found in section 7.1.2 Creation. In that example, the user has to understand that the charts represent volume levels at different points in time and not the complete volume level changes since the simulation model does not have a higher granularity than weeks.

It is also vital to understand that the charts on model level and total level are complementing each other. The total level charts can hide the fact that if the demand of one model is very high, and low for the rest, the volume level of the less requested models will not go down to zero. But when a total level chart is presented, the levels can be shown to be zero since the demand is very high on an aggregated level. An example of this is shown in Figure 80 and Figure 81 below. In Figure 80, which shows the total FGI volume for each week, weeks 9, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28 and 30 are empty. This makes it easy to believe that no models exist in the FGI in these weeks. However, this is not true. When inspecting Figure 81 it is clear that only the weeks 10, 12 and 14 are empty but the weeks 9, 16, 18 and so forth have volumes. The difference between the charts is due to their different detail levels. The aggregated chart, i.e. the total level chart, hides certain facts that only become visible on a model level. This also implies that even though an RPC seems to have several units in FGI when looking at the total level chart, it might not be the units that are requested. To conclude on this phenomenon, it is very important to take both charts into account when simulating.
Production Throughput

Another disadvantage is that the simulation model cannot optimise the throughput in the production since this would require iterative processes, which is not possible in Microsoft Excel (without using Visual Basic code) and requires integer optimisation. The simulation model is built in a way that it will always try to produce as many units as the capacity limitation in the production can handle. So, even though the forecast might be much lower than the capacity limitation the simulation model will try to fill all the slots in the production. This means that the users have to control the production by adjusting the capacity limitation. In Table 23 and Table 24 the two errors that might occur in the production throughput are demonstrated. Table 23 shows what could be avoided if an iterative method could have been used. If the simulation model would be perfect, the total volume produced should be 20 units. However, with the way the simulation model actually works, the volume becomes 19 units.

Table 23. Example of a Iteration Problem in Production Throughput

<table>
<thead>
<tr>
<th>Model</th>
<th># in Buffer</th>
<th>Production Capacity Limitation</th>
<th>Forecast</th>
<th>Split</th>
<th>Actual Volumes Produced</th>
<th>Actual Total Volume Produced</th>
<th>Possible Total Volume Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>14</td>
<td>25</td>
<td>5</td>
<td>5/10=50 % → 0.5*25=12.5 → 13 units</td>
<td>13 units</td>
<td>13+6=19</td>
<td>14+6=20</td>
</tr>
<tr>
<td>Model B</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5/10=50 % → 0.5*25=12.5 → 13 units</td>
<td>6 units</td>
<td></td>
<td>26</td>
</tr>
</tbody>
</table>

Table 24 demonstrates the problem that is due to a rounding error. If the simulation model would be perfect, the total volume produced should be 25 units. However, with the way the simulation model works, the volume becomes 26 units.
Table 24. Example of a Rounding Error in Production Throughput

<table>
<thead>
<tr>
<th>Model</th>
<th># in Buffer</th>
<th>Production Capacity Limitation</th>
<th>Forecast</th>
<th>Split</th>
<th>Actual Volumes Produced</th>
<th>Actual Total Volume Produced</th>
<th>Possible Total Volume Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>14</td>
<td>25</td>
<td>5</td>
<td>5/10=50% $\rightarrow$ 0.5*25=12.5 $\rightarrow$ 13 units</td>
<td>13 units</td>
<td>13+13=26</td>
<td>25 (the maximum volume is equal to the capacity limitation)</td>
</tr>
<tr>
<td>Model B</td>
<td>14</td>
<td>5</td>
<td>5</td>
<td>5/10=50% $\rightarrow$ 0.5*25=12.5 $\rightarrow$ 13 units</td>
<td>13 units</td>
<td>13+13=26</td>
<td>25 (the maximum volume is equal to the capacity limitation)</td>
</tr>
</tbody>
</table>

**Software**

The directive of using Microsoft Excel, and to an as large extent as possible avoid Visual Basic programming, certainly has an effect on the flexibility and robustness of the simulation model. Certain operations, such as iterative processes, are not feasible. Other operations are feasible but become very unclear for the next person who wants to understand the computations behind the simulation model. The programming language is quite difficult to present in a simple and structured way. Therefore, the authors have tried to complement the codes with decision trees and examples that can be found in the administrator manual.
9 CONCLUSIONS AND DISCUSSION

In this chapter the fulfilment of the purpose is evaluated. Also, general reflections upon the study are presented. The studied system and its different parts are put into a wider picture permitting a more extended analysis. The use of the study’s outputs is analysed and possible generalisations and potential for further development are explored. General recommendations regarding the use of the simulation model are given and in addition, suggestions for further research are presented.
9 Conclusions and Discussion

9.1 Fulfilment of the Purpose
As was stated in the beginning of the report, the purpose of the study is “to create a simulation model, based upon a process mapping, that visualises future volume levels in the pipeline due to different demand and ordering scenarios”. The purpose was accompanied by a short term target; to increase the RPCs understanding for how different demand and ordering scenarios influence the future volume levels in the pipeline. This was also the target of the study.

To begin with, a process mapping that started by a high level such and ended with a detailed level such has been carried out. Every major step from order placement made by the pipeline managers at the RPCs to the FGI at the RPCs has been mapped. The outcome from the process mapping was then analysed and generalised in order to define a starting point for the creation of a simulation model but before actually starting the simulation model creation, several elements had to be investigated. For example, user types, desired output and views, flexibility, level of approximation, identification of the mathematical relationships involved, user-friendliness and robustness had to be determined. When all this information had been collected and analysed the creation could start. The creation phase was an iterative process where the creators alternated between development and validation. Finally, the simulation model was tested by using a real case, having a test user trying it and by realising a sensitivity analysis. The tests showed that the simulation model works very well and only a couple of smaller modifications to it were made. The simulation model can therefore be considered to be both functional and present reliable results.

The simulation model has many functions that noticeably improve the possibility for the pipeline managers to get an increased understanding for how the goods move within the pipeline and how to improve the control of the volumes in it. The results of different order and demand scenarios are clearly visible in the charts that the simulation model generates and it is easy for the user to test different scenarios. More about the advantages of the simulation model can be found in section 8.2.1 Advantages.

With the above in mind, the authors deem that the purpose of the study has been fulfilled.

9.2 The Role of the Study

9.2.1 Future Development
The work that has been done prior to the development of the simulation model is of great importance if Scania would like to develop a more robust solution. The method that has been followed, the process mapping and the definitions of the relationships are all valuable parts in order to facilitate for future development of the simulation model.

9.2.2 Generalisation of the Study
Other employees within the MDO department, who are not directly connected to the RPCs and their pipelines, have expressed an interest in the simulation model since they believe that it might be possible to use it for their flows as well. Similarities between the flows explored in this study and other flows within MDO have been discovered and at least the methodology that has been used can be helpful if a comparable solution is to be developed for these similar flows. The authors believe that the simulation model is quite rigid and well-adapted for the specific case but it would probably not be fully applicable in other cases. An important aspect here, that is limiting the flexibility, is the fact that it is a Microsoft Excel solution. As van der Zee and van der Vorst (2005) mention, it is not
only the analyst’s skills and the chain members’ involvement that determine the success of a supply chain simulation but also the capabilities of the simulation tool.

When putting the study into a larger perspective, the authors believe that the methodology of the study could be useful for other companies or organisations that want to create a logistics simulation model based upon a process mapping. The framework combining the logistics area with mathematical modelling and simulation techniques can be considered well-functioning and the authors can recommend the use of it in similar cases.

9.3 Recommendations Regarding the Use of the Simulation Model
As Stock and Lambert (2001) claim, a model does not replace a decision making process, however it can support such and it can be useful for playing so called “what-if” games. The same authors also argue that simulation does not give an optimal solution but it can help management to establish satisfactory solutions from a number of alternatives. Hwarng et al. (2005) mention that when it comes to simplifications and assumptions, this can render large differences between reality and the model output and thus decision-makers should always remember to use both simulation and analytic frameworks. Law (2007) states that no matter how much effort that is spent on model creation, the model will still be an approximation of the system. This is valid for the simulation model that has been created in this study as well. The users should not take the simulation model’s output as the only truth, it is just as important that they use their common sense in order to analyse the situation. Furthermore, Christopher (2011) claims that the nature of a pipeline with long lead times makes it difficult to connect the manufacturing and procurement decisions to the market requirements in a visible way. The simulation model gives a very good hint about what will happen in the pipeline but, as was explained in section 8.2.2 Drawbacks, the simulation model is not a perfect tool.

9.4 Suggestions for Further Research

9.4.1 Inventory Management
The long term target that accompanied the purpose of this study is to reduce tied up capital by adjusting buffer levels and lead times, while still ensuring a certain service level. This implies that a comprehensive approach to the situation is required. Reichhart et al. (2008) claim that high delivery service and low costs should be strived for in the supply chain and that trade-offs are necessary. Stock and Lambert (2001) underline that one of the objectives of inventory management is to establish an inventory level needed for achieving the least total logistics cost while still being able to satisfy the customer service objectives. In this case, the service level is measured but since the non-satisfied demand is not registered no one really knows the real service level. This makes it difficult to connect the manufacturing and procurement decisions to the market requirements in a visible way. As Lumsden (2012) points out, it is important to consider the entirety when making logistics decisions. Hence, the authors think that the inventory management area would be an interesting area for further research.
9.4.2 Forecasts

The simulation model that has been created will hopefully facilitate the decision making regarding order volumes for pipeline managers at the RPCs. However, it is important to remember that in general, the quality of the output from a model is very dependent on the quality of the input.

In this study the forecast has been considered to be “correct” at every moment since this was a directive from the taskmaster. During the interviews that have been made during the process mapping part of the study, several comments regarding the forecast have been registered. Some of the interviewees claim that the forecast is nothing but a yearly sales target that has been broken down into a sales volume per month. This means that the forecast is a top-down product and the monthly update of it does not have much to do with the real market situation. One interviewee even said that “there is not a lot of science behind these forecasts”.

In the theoretical framework that is presented in this report, a couple of sections covering forecasts are presented. For example, Anupindi et al. (2012) claim that the degree of confidence in the forecast should be provided since forecasts are usually inaccurate. Lapide (2000) continues that statistical methods often are used when creating forecasts in order to identify patterns that can be useful when creating a new forecast. The authors have not got the impression that the forecasts used as input in the simulation model are based upon statistical methods, nor are they accompanied by a degree of confidence. The effort to continuously trying to improve the forecasts also seems quite limited. Also, Olhager (2000) stresses the fact that the need of forecasting increases if the OPP is placed late in the value chain. For the RPC markets, this is the case. Croxton et al. (2002) argue that it might be more suitable to aim for accurate forecasts than to increase flexibility in some industries. Thus, the forecast area appears to be interesting for further studies in order to find out which quality the forecasts actually have. No matter how well the pipeline managers adapt the pipeline volumes in order to meet the demand, the final result will always be wrong if forecasts lie too far from reality.

9.4.3 Interaction within the Supply Chain

This study focuses on a certain part of the supply chain at Scania. The primary focus is the RPCs and, as explained in the very beginning of the report, the process starts when an RPC receives a forecast and ends when the units are assembled and put in the FGI at the RPC. One of the objectives with the simulation model is to increase the understanding of the pipeline by visualising its contents in order to decrease tied up capital in a longer perspective. However, the RPC and the pipeline managers are not the only ones that can have an impact on the level of tied up capital.

When the units have been assembled they are waiting in the FGI to be delivered. It can take quite long time before the BU/distributor buys the units. If the units have not been bought and picked up after six months, the RPC pushes the units over to the BU/distributor and the BU/distributor is invoiced. When looking at the whole picture, six months is quite some time compared to a three to four months long lead time earlier in the chain. Even though both the RPC and the BU/distributor are parts of the Scania sphere, they are different profit centres and from that point of view they can be considered to be different players within a supply chain. Fawcett et al. (2008) claim that one of the barriers to a strategic supply chain management is the unwillingness to share risks and rewards. Hence, in a well-functioning supply chain, risks and rewards are recommended to be shared. This does not seem to be the case when looking at the RPCs and the BUs/distributors. If the BU/distributor provides forecasts with low quality, the RPC still has to own and store the units up to
six months. Therefore, it appears to be interesting to study the relationship between the different players in the supply chain, dig deeper into how risks and rewards are shared and what the incentives are for each player to decrease the tied up capital.
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In this chapter the written, electronic and oral sources that have been used during the study are presented.
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In this part the appendices that are adequate for the study are attached.
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<tr>
<td>Table 42.</td>
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<td>XLI</td>
</tr>
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<td>XLI</td>
</tr>
<tr>
<td>Table 44.</td>
<td>Settings for Test 8 - Part 1</td>
<td>XLIII</td>
</tr>
<tr>
<td>Table 45.</td>
<td>Settings for Test 8 - Part 2</td>
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</tr>
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<td>Table 46.</td>
<td>Test Data Set 8</td>
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</tr>
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<td>Table 47.</td>
<td>Settings for Test 9</td>
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<td>Table 48.</td>
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</tr>
</tbody>
</table>
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Appendices

Appendix II. Supply Chain Processes

Demand Management

Strategic and operational parts are both included in the demand management process, as can be seen in Figure 82 below. The aim of the strategic process is to design the operational system, while the operational process executes what has been designed. Below, the six strategic sub-processes and the five operational sub-processes are described. (Croxton et al., 2002)

![Figure 82. Demand Management (Source: Croxton et al., 2002)](image)

**Determine demand management goals and strategy:** This sub-process ensures that the aims and the focus of the demand management process are agreed upon and generates a structure for the demand management process. Many aspects have to be taken into account, e.g. the company’s overall strategy, the customers’ needs, the manufacturing capabilities and the supply chain system, in order to find the most suitable goals for the specific company and industry. (Croxton et al., 2002)

**Determine forecasting procedures:** In this part of the strategic process, it is decided how forecasting should be carried out and what the characteristics of the forecasts should be. The first characteristics that have to be determined are the level of the forecasts, e.g. level of aggregation and the time frames of the forecasts (e.g. long, medium or short term). Depending on which part of the company that is going to use the forecasts, they might need to have different levels and time frames. Even though several forecasts might be created within the same company, they have to be consistent and show the same future scenarios. Secondly, appropriate sources of information that can be used in order to create the forecasts need to be identified. Thirdly, the forecasting method for each forecast has to be set. A forecast can be qualitative and contain human input or quantitative and data driven. Finally, the team has to decide upon how often the forecasting procedure should be reviewed. (Croxton et al., 2002)
Plan information flow: In this sub-process the data sources are settled and it is defined how the information should be transferred. Moreover, it is decided to whom different outputs should be communicated. In addition to this, further information sharing possibilities should be explored, the input and output data could be used when future business strategy will be set e.g. (Croxton et al., 2002)

Determine synchronisation procedures: This sub-process is often called S&OP. The main task within the process is to determine which synchronisation procedures that should be in place in order to “match the demand forecast to the supply chain’s manufacturing and logistics capabilities” (Croxton et al., 2002, p.57). Figure 83 depicts this synchronisation, which results in a demand execution plan. One element of the synchronisation process is to set up rules for where inventory should be when the demand weakens and how it should be moved when the demand increases. It is also important to carefully investigate where capacity limitations occur or may occur, as well as exploring the flexibilities. Different products may need different synchronisation procedures. New products may e.g. need to be treated in a different way since in can be difficult to predict the demand. (Croxton et al., 2002)

![Figure 83. Synchronising the Supply Chain (Source: Croxton et al., 2002)](image)

Develop contingency management system: If unexpected events occur it is important to have a plan for how to handle this and how to react. This is what the contingency management system is for. An example of an unexpected event could be a production stop. Collaboration with other supply chain sub-processes is required when developing the contingency management system, e.g. customer relation management and order fulfilment. (Croxton et al., 2002)

Develop framework of metrics: The performance of the demand management process needs to be measured in able to make improvements. Demand management affects several financial measures within the company. For example, it influences sales, total expenses, current assets, cost of goods sold, inventory investment as well as fixed assets. Higher service level to the customers probably generates an increase in sales, improved scheduling can reduce the manufacturing costs and enhanced demand management can reduce safety stocks and obsolete inventory to mention a few financial relationships. Other supply chain processes can affect the performance of the demand management but it is still important to be able to show and measure the performance. It is important to remember that the goal of the supply chain management is to increase profitability for
all companies in the supply chain and not only the own company. Risks and rewards should be
shared and a win-win situation should be strived for. (Croxton et al., 2002)

The operational part of the demand management process basically executes what has been designed
in the strategic part. As can be seen in Figure 82 the operational demand management process
contains five main sub-processes. (Croxton et al., 2002)

Firstly, collection of required data and information in order to create the forecasts is done. Secondly,
the forecasts are created and what is important here is that the forecasts errors from earlier on are
measured and taken into account when the new ones are made. This is how forecasts are
continuously improved. Thirdly, synchronisation is done, which means that the demand is matched
with the supply and the demand execution plan is set. Several aspects are taken into account, such as
capacity and financial limitations and current inventory levels. When these aspects are known,
demand is being prioritised, bottlenecks resolved and appropriate resources allocated. Computing
confidence intervals of the forecasts gives useful information to the synchronisation process. For
example the customer service levels can be determined and decisions regarding how much of the
demand the company wants to meet can be made. (Croxton et al., 2002)

The fourth sub-process includes variability reduction and flexibility increase, which both are main
components of demand management. A supply chain contains several sources of variability and
demand is one important such. What separates demand planning from demand management is the
fact that demand management actively seeks to reduce variability by finding its root causes and
solutions to these and thereby giving an as smooth input as possible to demand planning. Common
reasons to demand variability are e.g. internal problems such as end-of-quarter loads, introduction
of new products, pricing, consumer promotions and long distribution channels. Many of these can be
solved by e.g. collaborating more intensively with the marketing department or incorporating
demand variability into the supply chain network. Increasing flexibility often implies important costs
and this is why reduction of variability should be strived for as far as possible. The variability that
cannot be removed should be compensated for by increased flexibility. It is important that flexibility
is built in where it is needed the most, e.g. where bottlenecks have been identified. The last sub-
process is to measure performance of the operational demand management process. (Croxton et al.,
2002)

**Order Fulfilment**

Order fulfilment is another process within supply chain management. A combination of the
company's manufacturing, logistics and marketing plans is necessary in order to conduct effective
order fulfilment. It is also necessary to create partnerships between key parts of the supply chain;
these can ensure that customer requirements are met and that the total cost is reduced for the
customers. The order fulfilment process contains a strategic part as well as an operational such.
(Croxton et al., 2001)

Croxton has developed the order fulfilment process in deep in the article The Order Fulfillment
Process (2003). Figure 84 originates from this article.
The strategic order fulfilment process consists of several sub-processes. First, the marketing strategy, the supply chain structure and the customer service and goals are reviewed. Second, the requirements for order fulfilment are defined. Order fulfilment core competencies are identified and possible differentiating parts of the process regarding the service provided to the customer can be found. Other important contributions to this step in the process are lead times, manufacturing capabilities as well as customer service requirements. Third, the logistics network is assessed, since this has major effect on the system’s cost and performance. Multiple factors should be taken into account during the evaluation, e.g. where production sites, suppliers and warehouses are situated. The output from this step, a new network, is given to the manufacturing flow process. Fourth, a plan for order fulfilment is defined. The plan shows how customers’ orders will be filled and how customer relationship management gives important input to this process. A framework of metrics is developed in the last sub-process. To conclude, it is important to understand internal as well as external requirements and make sure that the capabilities of the system are adequate. Customer service requirements and the business plan are major input to the creation of a well-functioning supply chain network that can meet the customer’s needs. The system has to be able to handle situations where supply is smaller than demand and the customer service is hard to maintain. (Croxton et al., 2001)

The operational order fulfilment process starts with order generation and communication. This is followed by order entering, order processing, documentation handling, order picking, order delivery and finally post-delivery activities and performance measurement. (Croxton et al., 2001)

The authors also describe how the order fulfilment process frequently is regarded as simply a transactional part of the logistics function, while it actually has many strategic components in it and is cross-functional. (Croxton et al., 2001)
Appendices

Appendix III. The Difference between Validation and Output Analysis

In this appendix, the information and the example originate from Law (2007) if nothing else is indicated.

Validation is about obtaining a model output as close to the system output as possible (still being cost-effective) while output analysis serves as a basis to improve every single simulation output to be as close to the model output as possible. To better understand the difference between validation and output analysis an example is presented below.

Suppose that an estimation of the mean of a system \( \mu_S \) is wanted. If the corresponding mean of the model is indicated \( \mu_M \) and the mean of a simulation run is indicated \( \hat{\mu}_M \) the error in \( \hat{\mu}_M \) is an estimate of \( \mu_S \) given by the following equation:

\[
\text{Estimation error in } \hat{\mu}_M = \left| \hat{\mu}_M - \mu_S \right| = \left| \hat{\mu}_M + (\mu_M - \mu_M) - \mu_S \right| = \left| \hat{\mu}_M - \mu_M + \mu_M - \mu_S \right| \leq \left| \hat{\mu}_M - \mu_M \right| + \left| \mu_M - \mu_S \right|
\]

where the last equality (\( \leq \)) is given by the triangle inequality.

Output analysis should make the first absolute value small while validation should make the second absolute value small. Regardless, both are needed to obtain a good model.
Appendix IV. Initial Assignment from Scania

Optimized pipeline management

The MD organization offers Scania’s business units the possibility to focus on their core business by taking responsibility for all after factory activities. The business covers 4 main areas: Outbound, Complete Vehicle Logistics, CKD/SKD operations and Regional Product Centres (RPC).

Background
Scania has seven Regional Product Centres (RPC’s) over the world, located in South Africa, Malaysia, Thailand, Taiwan, Dubai, Russia and Korea. A new RPC is under establishment in India. The service provided by the RPC’s is logistic governance of all deliveries from Scania factories, assembly of component kits, adaptations, body building, PDI and delivery to customer. In order to reduce delivery lead time to the market, the RPC has also offered to keep a certain number of standard models for the market in stock at RPC, volume decided by sales forecast. As the accuracy of a sales forecast always depends on the present situation on the market, it is hard to always have the correct volume in stock. Big or sudden increases or decreases in demand strikes hard on buffers and lead time.

Target
Secure deliveries to end customer and reduce tied up capital, by optimizing buffer levels and reducing lead time for overseas markets with Regional Product Centres.

Assignment
Create a visual method and a tool to simulate different scenarios of demand and ordering for refill models at a RPC. In the method it should also be possible to optimize stock levels and buffer time. Several different parameters must be possible to take into consideration in the simulation.

Education
Master of science or equivalent education within logistics/optimization.

Number of students: 1-2 students
Start date: Spring 2013
Estimated time needed: 20 weeks

Contact persons and supervisors
Hans Ekman, Manager of Global outbound logistics, Södertälje +46 8 553 812 81,
Annamari Balaze, Pipeline manager Regional Product Centers, Södertälje, +46 8 553 523 21
Appendices

Appendix V. Structured Literature Search

The structured literature search follows the five steps by Rumsey (2008) presented in section 4.2.2 Theoretical Framework. Identifying search terms, which is the first literature searching step, was done during the problem background formulation. Furthermore, when the initial Internet search was done, some theoretical areas were found interesting. The search terms are presented in Table 25.

Table 25. Structured Literature Search – Search Terms

<table>
<thead>
<tr>
<th>Search Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
</tr>
<tr>
<td>Complete knock down</td>
</tr>
<tr>
<td>Demand management</td>
</tr>
<tr>
<td>Descriptive model</td>
</tr>
<tr>
<td>Inventory level</td>
</tr>
<tr>
<td>Long lead time</td>
</tr>
<tr>
<td>Mapping</td>
</tr>
<tr>
<td>Overseas</td>
</tr>
<tr>
<td>Pipeline management</td>
</tr>
<tr>
<td>Simulation model</td>
</tr>
<tr>
<td>Supply chain</td>
</tr>
</tbody>
</table>

The second step in the literature searching process was in this case neglected since the researchers did not want to narrow the search too much in the beginning. Thirdly, the search terms were truncated and the terms presented in Table 26 were acquired.

Table 26. Structured Literature Search – Truncated Search Terms

<table>
<thead>
<tr>
<th>Truncated Search Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
</tr>
<tr>
<td>Complete knock down</td>
</tr>
<tr>
<td>Demand management</td>
</tr>
<tr>
<td>Descriptive model*</td>
</tr>
<tr>
<td>Inventory level*</td>
</tr>
<tr>
<td>Long lead time*</td>
</tr>
<tr>
<td>Mapping</td>
</tr>
<tr>
<td>Overseas</td>
</tr>
<tr>
<td>Pipeline management</td>
</tr>
<tr>
<td>Simulation model*</td>
</tr>
<tr>
<td>Supply chain*</td>
</tr>
</tbody>
</table>

When the search terms had been truncated, they were combined with Boolean logic. Firstly, some of the terms were categorised as general supply chain search terms. Secondly, the others were split into specific logistics search terms and modelling search terms. These categories are presented in Table 27.
The terms were combined with one term from the general supply chain category and one term from one of the others. To decide which database to use, the researchers made a search with the general supply chain search terms, following up in which database the highest number of hits were received. In Table 28, the number of hits is presented and from this table it follows that Business Source Premier got more hits than the others, why this database was used in the study.

The fifth step of the literature search process, combining terms 2 (using connectors) was not used since the search already was narrowed enough to give a sufficient number of hits. The received hits and how many of these that was considered relevant are presented in Table 29. The titles and abstracts of the articles were read whereupon the relevance of the articles was evaluated.

---

Table 27. Structured Literature Search – Categorised Search Terms

<table>
<thead>
<tr>
<th>Supply Chain – General</th>
<th>Logistics – Specific</th>
<th>Modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast</td>
<td>Complete knock down</td>
<td>Descriptive model*</td>
</tr>
<tr>
<td>Inventory level*</td>
<td>Demand management</td>
<td>Mapping</td>
</tr>
<tr>
<td>Long lead time*</td>
<td>Pipeline management</td>
<td>Simulation model*</td>
</tr>
<tr>
<td>Supply chain*</td>
<td>Overseas</td>
<td></td>
</tr>
</tbody>
</table>

Table 28. Structured Literature Search – Number of Hits in Different Databases

<table>
<thead>
<tr>
<th>Database</th>
<th>Fields</th>
<th>&quot;Supply chain&quot;</th>
<th>&quot;Long lead time&quot;</th>
<th>&quot;Inventory levels&quot;</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSP1</td>
<td>TX All Text</td>
<td>173,257</td>
<td>4,743</td>
<td>16,563</td>
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<td>Scopus</td>
<td>All Fields</td>
<td>76,186</td>
<td>1,012</td>
<td>3,013</td>
<td>172,565</td>
</tr>
<tr>
<td>Emerald</td>
<td>All Content</td>
<td>12,260</td>
<td>239</td>
<td>604</td>
<td>10,202</td>
</tr>
<tr>
<td>ASP2</td>
<td>All Text</td>
<td>38,502</td>
<td>2,095</td>
<td>3,256</td>
<td>272,057</td>
</tr>
</tbody>
</table>

Table 29. Structured Literature Search – Searches, Number of Hits and Number Relevant Hits

<table>
<thead>
<tr>
<th>Search term</th>
<th>Fields</th>
<th>Hits</th>
<th>Relevant</th>
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</thead>
<tbody>
<tr>
<td>&quot;Inventory level** AND &quot;Complete knock down&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Inventory level** AND &quot;Demand management&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
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<td>0</td>
</tr>
<tr>
<td>&quot;Inventory level** AND &quot;Descriptive model***&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Inventory level** AND &quot;Pipeline management&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Inventory level** AND &quot;Simulation model***&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>38</td>
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</tr>
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<td>&quot;Inventory level** AND Mapping&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>4</td>
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</tr>
<tr>
<td>&quot;Inventory level** AND Overseas</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>3</td>
<td>0</td>
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<tr>
<td>&quot;Long lead time** AND &quot;Complete knock down&quot;</td>
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<td>0</td>
</tr>
<tr>
<td>&quot;Long lead time** AND &quot;Demand management&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Long lead time** AND &quot;Descriptive model***&quot;</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>0</td>
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<td>AB Abstract or Author-Supplied Abstract</td>
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<td>5</td>
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<td>&quot;Supply chain** AND Mapping*</td>
<td>AB Abstract or Author-Supplied Abstract</td>
<td>127</td>
<td>3</td>
</tr>
</tbody>
</table>

1 Business Source Premier
2 Academic Source Premier
In Table 30, the relevant articles are presented. These articles have been read and have in many cases served as a basis for further direct article searches, e.g. by checking their references.
## Table 30. Structured Literature Search – Relevant Hits

<table>
<thead>
<tr>
<th>Reference</th>
<th>Search Code</th>
<th>Cited References</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leavy, B. (1988) The Production and Inventory Management and Strategy Fields - A Case for more Dialog, Production &amp; Inventory Management Journal; Vol. 29 Issue 1, p61-64</td>
<td>Forecast AND &quot;Demand management&quot;</td>
<td>13</td>
<td>No</td>
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<td>chain practices—The impact of demand and distribution management on</td>
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<td>supply chain success, Journal of Operations Management; Vol. 30 Issue</td>
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<tr>
<td>4, p269-281</td>
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<td>approach for the performance analysis of a serial multi-echelon supply</td>
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<td>chain, International Journal of Production Research; Vol. 50 Issue 9,</td>
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<td>p2380-2395</td>
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<td>Framework for Supply Chain Simulation: Opportunities for Improved</td>
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<td>Decision Making, Decision Sciences; Vol. 36 Issue 1, p65-95</td>
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<td>process reengineering in implementing global supply chain systems by</td>
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<td>the SCOR model, International Journal of Production Research; Vol. 48</td>
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<td>Issue 19, p5647-5669</td>
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<td>delivery lead time for a supply chain system, International Journal</td>
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<tr>
<td>of Systems Science; Vol. 39 Issue 12, p1193-1202</td>
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</tbody>
</table>
Appendix VI. Library Literature Search

The main shelves that were searched in the libraries are presented in Table 31. These shelves have been visited several times at the library at Linköping University and some of them at library at the Royal Institute of Technology. The Royal Institute of Technology were normally used to find literature that was requested by the authors and not available at the library at Linköping University.

Table 31. Literature Search – Library Shelves

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
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<tr>
<td>001.4</td>
<td>Research; Statistical Methods</td>
</tr>
<tr>
<td>003</td>
<td>Systems</td>
</tr>
<tr>
<td>300.72</td>
<td>Research Methodology in the Social Sciences</td>
</tr>
<tr>
<td>658.4</td>
<td>Executive Management</td>
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<td>Management of Production</td>
</tr>
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<td>658.7</td>
<td>Management of Materials</td>
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</table>
Appendices

Appendix VII. Interview Guides and Focus Group Material

Interview – High Level Mapping

Place: Scania Södertälje

Date and Time: Tuesday 4th of March 2013, 15.00-16.00

Type of Interview: In person

Interviewees: Annmari Balázs, Pipeline Manager Regional Product Centres, MDO
Hans Ekman, Manager Global Outbound Logistics, MDO

Interviewers: Elin Ovesson
Niklas Stadler

Questions

The questions below were asked for each RPC.

1. Where, or by what, do you think that the process starts?
2. Where, or by what, do you think that the process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which is/are the PRU(s) providing the RPC?

When a summary of all the RPCs has been put together according to Table 2 presented in section 4.2.5 Data Collection and Analysis and Execution, the following questions were asked.

6. With this summary in mind, which of the flows do you think can be regarded as similar?
   a. Could you explain, if some of them are considered not to be similar, what differs between them if this is not evident in the summary?
7. Do you have any suggestions of what can be generalised in the process?
8. Do you have any suggestions of what should definitely not be generalised in the process?
Interview – Detailed Mapping – KXV

Place: Scania Södertälje, CK3 Plan 3 Trollstaven

Date and Time: Tuesday 11th of March 2013, 14.00-15.30

Type of Interview: In person

Interviewees: Lina Wigermo, Business Development Manager, Volume Planning, KXV
Jakob Wijkström, Volume Analyst Trucks, Volume Planning, KXV

Interviewers: Elin Ovesson
Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities

Questions

The questions below were asked for each RPC chosen to be mapped in detail.

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
13. Which activities do you think can be labelled as “bottlenecks”?

Finish

- Conclude on the processes
Appendices

Interview – Detailed Mapping – Order Office

Place: Scania Södertälje, CK3-03

Date and Time: Tuesday 5th of March 2013, 14.00-15.30

Type of Interview: In person

Interviewees: Ove Karlsson, Team Leader/Senior Order Coordinator, Chassis Order Control, TPOC
Per Tulldahl, System manager PRAL, Order Logistics, TPO

Interviewers: Elin Ovesson
Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  o Confirm titles
  o Confirm departments
  o Responsibilities

Questions

The questions below were asked for each RPC chosen to be mapped in detail.

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
13. Which activities do you think can be labelled as “bottlenecks”?

Finish

- Conclude on the processes
Interview – Detailed Mapping – Production and Packing

Place: Scania Södertälje

Date and Time: Tuesday 11th of March 2013, 10.00-11.00

Type of Interview: In person

Interviewees: Elias Malki, Manager KD Packing, KD Packing, MSDK

Interviewers: Elin Ovesson
             Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  o Confirm titles
  o Confirm departments
  o Responsibilities

Questions

The questions below were asked for each RPC chosen to be mapped in detail.

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
13. Which activities do you think can be labelled as “bottlenecks”?

Finish

Conclude on the processes
Appendices

Interview – Detailed Mapping – Delivery

Place: Scania Södertälje, B230 CRK3S

Date and Time: Wednesday 6th of March 2013, 9.30-10.30

Type of Interview: In person

Interviewees: Merja Kaski, Delivery Planner, Chassis Delivery and Delivery Service Desk, MSDL

Interviewers: Elin Ovesson
            Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities

Questions

The questions below were asked for each RPC chosen to be mapped in detail.

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
13. Which activities do you think can be labelled as “bottlenecks”?

Finish

- Conclude on the processes
Appendices

Interview – Detailed Mapping – RPC Russia

Place: Scania Södertälje (Interviewers)

Date and Time: Tuesday 26th of March 2013, 12.00-13.30

Type of Interview: Telco

Interviewees: Margarita Goldina, Senior Planning Specialist, Regional Product Centre Russia, MDR

Interviewers: Elin Ovesson

Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities
- The interviewee presents herself.

Questions

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
   a. What capacity limitation do you have in your production?
   b. What flexibility do you have in your production?
13. Which activities do you think can be labelled as “bottlenecks”?
14. When is the responsibility for the goods yours?
15. What do you take into account when placing an order? (Capacity, lead time, forecast...)
16. If you were given a simulation model, which views would you like to get? (Buffer levels, stock levels...)

Finish

- Conclude on the processes.
Appendices

Interview – Detailed Mapping – RPC South Africa

Place: Scania Södertälje (interviewers)
Date and Time: Tuesday 19th of March 2013, 10.00-11.30
Type of Interview: Telco
Interviewees: Tommy Svensson, RPC Director, Regional Product Centre South Africa, MDZ
Interviewers: Elin Ovesson, Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities
- The interviewee presents himself.

Questions

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
   a. What capacity limitation do you have in your production?
   b. What flexibility do you have in your production?
13. Which activities do you think can be labelled as “bottlenecks”?
14. When is the responsibility for the goods yours?
15. What do you take into account when placing an order? (Capacity, lead time, forecast...)
16. If you were given a simulation model, which views would you like to get? (Buffer levels, stock levels...)

Finish

- Conclude on the processes
Appendices

Interview – Detailed Mapping – General KD Process

Place: Scania Södertälje (interviewers)

Date and Time: Tuesday 19th of March 2013, 15.00-16.30

Type of Interview: Telco

Interviewees:
- Fabio del Nery, Manager KD operations and Outbound, KD/Outbound Organisation, TLMKD
- Eduardo de Paula Silva, Head of KD Development & Engineering, KD Development and Engineering, LMKD

Interviewers: Elin Ovesson
- Niklas Stadler

Introduction
- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities
- The interviewees present themselves.

Questions
The questions below were asked for each RPC.

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
   a. What is the input to each activity?
   b. What is the output from each activity?
   c. Verification: Do the inputs and outputs link the activities?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
13. Which activities do you think can be labelled as “bottlenecks”?

Finish
- Conclude on the processes
Appendices

Interview – Detailed Mapping – General RPC and Pipeline Process

Place: Scania Södertälje (interviewer)

Date and Time: Wednesday 4\textsuperscript{th} of April 2013, 9.00-10.00

Type of Interview: Telco

Interviewees: Ino Moberg, Manager, Regional Product Centre Korea, MDK and Taiwan, MDT

Interviewers: Niklas Stadler

Introduction

- Short introduction to the Master’s Thesis.
- The interviewees are asked to present themselves and their roles at Scania.
  - Confirm titles
  - Confirm departments
  - Responsibilities
- The interviewees present themselves.

Questions

1. Where, or by what, do you think that your process starts?
2. Where, or by what, do you think that your process ends?
3. Which main activities do you identify between the beginning and the end?
4. Which products or product categories constitutes the physical flow?
5. Which are the product volumes?
6. How do the product volumes vary?
7. Which are the decision points in the flow?
8. Which formal information systems support the flow?
9. Which informal information systems support the flow?
10. Which are the lead times for each activity in the process?
11. How do the lead times for each activity vary?
12. Which are the capacity limitations for each activity?
   a. What capacity limitation do you have in your production?
   b. What flexibility do you have in your production?
13. Which activities do you think can be labelled as “bottlenecks”?
14. When is the responsibility for the goods yours?
15. What do you take into account when placing an order? (Capacity, lead time, forecast...)
16. If you were given a simulation model, which views would you like to get? (Buffer levels, stock levels...)

Finish

- Conclude on the processes
Focus Group – Mapping Verification

Place: Scania Södertälje

Date and Time: Tuesday 26th of March 2013, 10.00-11.00

Attendees: Thomas Eriksson, Project Manager KD/SKD Operation & Industrial Establishments, Engineering, MDE
Jenny Hedman, Process Development, Global Outbound Logistics, MDO
Emma Lindgren, Complete Vehicles Logistics Manager, Global Outbound Logistics, MDO

Focus Group Leaders: Elin Ovesson
Niklas Stadler

1. Short introduction of the Master’s Thesis.
2. Present the goal of the focus group: Create a common view of the process.
3. Let everyone present their view of the pipeline by drawing on a blank sheet.
4. Present the previously made function mapping.
5. Discussion and merger of the individual views and the function mapping.
6. Discussion of questions.
   a. Which are the most common deviations in the process?
   b. What in the process works normally without any deviations?
   c. Which are the greatest challenges in the flows?
Focus Group – Requirement Specification

Place: Scania Södertälje

Date and Time: Weekly 11th of March - 15th of April 2013

Attendees: Annmari Balázs
            Hans Ekman

Focus Group Leaders: Elin Ovesson
                      Niklas Stadler

1. Anchor what has been found during the previous focus groups.
2. Discuss the questions 2.1, 2.2, 2.3 and 2.4.
Appendix VIII. Sensitivity Analysis
For all tests that have been made in the sensitivity analysis, the lead times in Table 32 have been used. The lead times for the buffer inventory and the FGI are locked in the simulation model to be one week each, therefore they were also chosen to be one week for the tests. The other lead times are chosen randomly but they are still realistic.

Table 32. Lead Time Settings for all Tests

<table>
<thead>
<tr>
<th>Activity</th>
<th>Weeks</th>
<th>Aggregation</th>
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<tbody>
<tr>
<td>Order</td>
<td>3</td>
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</tr>
<tr>
<td>Production and Packing</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Transportation</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Arrival at Port</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Buffer Inventory</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Production</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>FGI</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

Test 1-5: Basic Functionality
For the first four tests, the settings in Table 33 were used. Three refill truck models, Model A-C, have been used in the tests.

Table 33. Settings for Test 1-4

<table>
<thead>
<tr>
<th></th>
<th>Capacity Limitation Transportation</th>
<th>Capacity Limitation Arrival at Port</th>
<th>Capacity Limitation Buffer Inventory</th>
<th>Capacity Limitation Production</th>
<th>Lag</th>
<th>Forecast Variation</th>
<th>Test Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>21</td>
<td>0 %</td>
<td>0 %</td>
<td>1-4</td>
</tr>
</tbody>
</table>

In the first test, the current status is set to be equal to the forecast and the order volumes are equal to zero, which can be seen in Table 34. Since the capacity limitation in the production is 21 units per week and the total forecasted weekly demand is 21 units, everything will pass through the production. Please note that in all tests presented below, the statuses are not in week 1-30 but for each activity week 1-14 (the total pipeline lead time). This is marked by a bold line between the statuses and the rest of the table.

The simulation model should return an empty buffer inventory in week 12 and an empty FGI in week 14 since no orders have been placed. Before the stocks become empty, the levels should steady be 7, 11 and 3 for each model respectively. The reason why the levels are constant is that the input volumes are equal to the output volumes. The volume levels of 7, 11 and 3 are due to the current status volumes that were entered in the buffer inventory as well as FGI at the very beginning.

Table 34. Test Data Set 1

<table>
<thead>
<tr>
<th>Test Data Set 1</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>7</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>7</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

In Figure 85 and Figure 86 the results from the first test are shown and it is clear that the simulation model output works correctly given the settings and test data set 1.
In the second test, the current status is also set to be equal to the forecast but the order volumes have been changed to 6, 12 and 3, which can be seen in Table 35. This means that Model A has a lower order volume than the forecast and Model B has a higher order volume than the forecast. Model C’s order volume still corresponds to the forecast and the total order volume is still 21. The capacity limitation in the production has not been changed which means that the total forecasted weekly demand of 21 units will pass.

The simulation model should return constant volume levels of 7, 11 and 3 in both buffer inventory and FGI until week 12 and 14 as explained above. When the first orders start to arrive in the buffer inventory, too few units of Model A and too many units of Model B will arrive compared to what is forecasted. In week 11 the last current status volume (7, 11 and 3) is present in the buffer inventory and the production is 7, 11 and 3. Then, in week 12 the ordered volumes arrive (6, 12, and 3) but the
production is still 7, 11 and 3. In the following weeks, only 6 units of Model A are available in the buffer inventory and thus only 6 units will be produced. On the contrary, 12 units of Model B exist and thus 12 units will be produced even though the forecasted demand is 11. The reasoning behind this can be found in section 6.3.1 Relationships between the Variables and Parameters. This implies an increase of the constant volume level for Model B to 12 units and a decrease of the constant volume level for Model A to 6 units in the buffer inventory. In the FGI, the volume levels will change because of the changed production volumes. Too many units of Model B and too few units of Model A will be produced compared to the forecast. This will lead to a steady decrease of the volume level of Model A of one unit per week in the FGI and a steady increase of the volume level of Model B of one unit per week. Model C will not be affected.

Table 35. Test Data Set 2

<table>
<thead>
<tr>
<th>Test Data Set 2</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>7</td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>3</td>
<td>21</td>
<td>7</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

In Figure 87 and Figure 88 the results from the second test are shown and it is clear that the simulation model works correctly given the settings and test data set 2.
In the third test, the current status is set to be different from the forecast and the order volumes have been set to zero, which can be seen in Table 35. The capacity limitation in the production has not been changed which means that the total forecasted weekly demand of 21 units will pass. Since no orders are placed the volume level in the buffer inventory will decrease to zero in week 12. The status volumes do not match the forecast volumes for Model A and Model B, which will have an effect on the production. For Model A, units are missing in the buffer inventory and thus only 7 units can be produced even though the forecasted volume is 8 units. For Model B, the inverse is valid, i.e. 11 units are available but only 10 units are forecasted. This results in a growing volume level in the FGI for Model B, while the volume level for Model A will decrease with one unit per week. Model C rests unchanged. The same effect that was caused by a non-existing order volume that can be observed in the buffer inventory will be seen in the FGI. So, even though the volume level of Model B in the FGI will increase to start with, it will decrease when no units are available in the buffer inventory.

Table 36. Test Data Set 3

<table>
<thead>
<tr>
<th>Test Data Set 3</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>8</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>7</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

In Figure 89 and Figure 90 the results from the third test are shown and it is clear that the simulation model output works correctly given the settings and test data set 3.
In the fourth test, the current status is set zero and the forecast equals the order volume, which can be observed in Table 37. The capacity limitation in the production has not been changed which means that the total forecasted weekly demand of 21 units will pass. Since the status is zero, the buffer inventory as well as the FGI will be zero until the first order arrives in week 12 for the buffer inventory and week 14 for the FGI. Thereafter the volume level in the buffer inventory will increase to a constant level. Nothing will be visible in the FGI since the forecast is equal to the volumes that enter. A deeper explanation of why the volume levels in the buffer inventory and the FGI look the way they do can be found in section 7.1.2 Creation.
Appendices

Table 37. Test Data Set 4

<table>
<thead>
<tr>
<th>Test Data Set 4</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>7</td>
<td>11</td>
<td>3</td>
<td>7</td>
<td>11</td>
<td>3</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In Figure 91 and Figure 92 the results from the fourth test are shown and it is clear that the simulation model works correctly given the settings and test data set 4.

Figure 91. Test 4 – Buffer Inventory

Figure 92. Test 4 – FGI

In the fifth test, new settings have been introduced. The capacity limitation in the production is changed in week 17 from 21 units per week to 27 units per week. These new settings can be viewed in Table 38.
In the fifth test, the current status is set to 7, 11 and 3 for the whole period while the forecast is set to 7, 11 and 3 for the weeks 1-16 and then 9, 12 and 6 for the weeks 17-30. The order volumes are 9, 12 and 6 for the whole period. This can be seen in Table 39.

To start with, the volume levels should be constantly 7, 11 and 3 for each model respectively in both the buffer inventory and the FGI since the volume levels in the current status corresponds to the forecasted volumes. In week 12, the first ordered volumes arrive whereupon the buffer inventory level will increase since these are higher than the forecast and the capacity limitation in the production. This will continue until week 16. In week 17 the production capacity limitation is changed to 27 units per week and the forecast is also adjusted. This combination of modifications results in a new equilibrium (17, 16 and 18). In the FGI, nothing will happen in week 12 when the orders arrive since the forecast is not changed and enough units are available in the buffer inventory. In week 16, 7, 11, and 3 units are produced and in the week that follows the forecast is 9, 12 and 6. When the forecast is changed the volume level in the FGI will decrease since more units are taken out than what arrive from the production. During the following weeks, when the capacity limitation in the production has been increased, a new equilibrium is reached (5, 10 and 0) in the FGI.

Table 38. Settings for Test 5

<table>
<thead>
<tr>
<th>Week 1-16</th>
<th>Capacity Limitation Transportation</th>
<th>Capacity Limitation Arrival at Port</th>
<th>Capacity Limitation Buffer Inventory</th>
<th>Capacity Limitation Production</th>
<th>Lag</th>
<th>Forecast Variation</th>
<th>Test Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 17-30</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>21</td>
<td>0 %</td>
<td>0 %</td>
<td>5</td>
</tr>
</tbody>
</table>

In Figure 93 and Figure 94 the results from the fifth test are shown and it is clear that the simulation model works correctly given the settings and test data set 5.
To conclude, the basic functionality that has been tested in test 1-5 works well.

**Test 6-8: Capacity Limitations, Forecast Variation and Lag Factor**

In the sixth test the capacity limitations were tested. Instead of making the tests on a model level and for specific activities (e.g. buffer inventory over time or FGI over time) the total pipeline at different weeks was considered.

In Table 40 the settings for the sixth test are shown. The capacity limitation in the transportation alternates between infinity and zero. In arrival at port the capacity limitation is infinite. The capacity limitation in the buffer inventory is infinite except from week two and three where it is zero. The capacity limitation in the production is set to 10.
### Table 40. Settings for Test 6

<table>
<thead>
<tr>
<th></th>
<th>Capacity Limitation Transportation</th>
<th>Capacity Limitation Arrival at Port</th>
<th>Capacity Limitation Buffer Inventory</th>
<th>Capacity Limitation Production</th>
<th>Lag</th>
<th>Forecast Variation</th>
<th>Test Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>10</td>
<td>0 %</td>
<td>0 %</td>
<td>6</td>
</tr>
<tr>
<td>Week 2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 3</td>
<td>∞</td>
<td></td>
<td>∞</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 4-30</td>
<td>0/∞</td>
<td></td>
<td>∞</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In Table 41, the test data set for the sixth test can be seen. The production capacity limitation is set to 10 and the weekly forecast is 20. This leads to that the volume level in the FGI will steadily decrease with 10 units per week until it is empty.

### Table 41. Test Data Set 6

<table>
<thead>
<tr>
<th>Test Data Set 6</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Non Refill Truck</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Non Refill Truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 1-30</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

Since no capacity limitations exist in the order activity, ten new units should arrive in Order 1 every week. Given that the capacity limitation in the production is set to 10 and that 20 units arrive in the buffer, the volume level in the buffer inventory will grow from 20 to 30 units in week 1. When the authors inspected the charts with the results, an error was discovered. The error was linked to the computations that handle the capacity limitations. However, the error was easy to fix and the simulation model then worked properly. When inspecting the result in Figure 95, it can be concluded that the modified simulation model works given the settings and test data set 6.

![Total Pipeline Week 1](image)  

*Figure 95. Test 6 – Total Pipeline Week 1*
Appendices

During week two, the transportation and the buffer inventory capacity limitations are zero. This should lead to an increase of the volume level with 20 units in the precedent activities, which in this case are production and packing 2 and arrival at port 2. The simulation model’s output, which coincides with the expectation, is presented in Figure 96.

![Figure 96. Test 6 – Total Pipeline Week 2](image)

During the third week the buffer inventory is still closed leading to increased volume levels in arrival at port 2. On the other hand the transportation is now open and the goods can pass on to transportation 1. Transportation 2 should be empty since nothing existed in transportation 1 the previous week. In Figure 97 the predicted results can be seen and hence the simulation model still returns accurate results.

![Figure 97. Test 6 – Total Pipeline Week 3](image)
Some weeks later, the order volumes of 10 units per week have strongly affected the volume levels in the pipeline. The transportation is still closed every second week leading to deliveries of 20 units every second week to the arrival at port 1. The volume level in the buffer inventory will grow until the order volumes of ten units start to arrive. When this happens, the volume level will be stabilised. The simulation model’s output in week 10 is depicted in Figure 98.

![Figure 98. Test 6 – Total Pipeline Week 10](image)

In the seventh test, the forecast variation alternates every week between 40 % and -40 %. This is presented in Table 42.

<table>
<thead>
<tr>
<th>Test Data Set 7</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Non Refill Truck</td>
<td>Refill Truck</td>
<td>Refill Truck</td>
<td>Non Refill Truck</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Refill Truck</td>
<td>Non Refill Truck</td>
</tr>
<tr>
<td>Week 1-30</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

The results can be seen in Figure 99 and Figure 100 and they correspond to the previous reasoning. In Figure 100, it can be observed that the simulated deliveries (forecast ±40 %) are rounded up or down since only whole units can be handled.
In the eighth test, two different settings were used (Part 1 and Part 2). These can be seen in Table 44 and Table 45. The only difference between the two is that the lag factor has been changed from 0 % to 100 %.
### Table 44. Settings for Test 8 – Part 1

<table>
<thead>
<tr>
<th>Test Data Set 8</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Non Refill Bus</td>
<td>Refill Truck</td>
<td>Refill Bus</td>
<td>Non Refill Bus</td>
<td>Market Allocation</td>
<td>Status Model A</td>
<td>Status Model B</td>
<td>Status Model C</td>
</tr>
<tr>
<td>Week 1-30</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

The test data set in Table 46 was used for both Part 1 and Part 2 of the test. Supply and demand matches in the test data set but the capacity limitation in the production is set to ten. This means that a lack of units in the FGI will occur.

### Figure 101. Test 8, Part 1 – Buffer Inventory
In the second part of the eighth test the lag factor is 100%, which means that all demand that has not been fulfilled will be moved forward to the subsequent week. Therefore, the non-satisfied demand in week X will be added to the demand of week X+1. When the volume level in the FGI has reached zero for one model, the demand will start to increase due to the lag. This implies that the production percentage split will change. However, the number of units that will be produced might not be affected directly since the percentage split is transformed to an integer. In this case, the demand of Model A and Model B will grow and the split will at some point be changed to such an extent that Model C will be affected. In Figure 103 and Figure 104 the simulation model’s output for the given settings and test data set is shown and they correspond well to the rationale explained above.
The ninth test had quite simple settings, see Table 47. What makes the test special is the low capacity limitation in the production in combination with the low test data set values in Table 48.

<table>
<thead>
<tr>
<th>Capacity Limitation Transportation</th>
<th>Capacity Limitation Arrival at Port</th>
<th>Capacity Limitation Buffer Inventory</th>
<th>Capacity Limitation Production</th>
<th>Lag</th>
<th>Forecast Variation</th>
<th>Test Data Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>1</td>
<td>0 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

A weakness that the simulation model has is the production split and the rounding of these percentages to whole units. The phenomenon is explained in deep in 6.3.1 Relationships between the Variables and Parameters. In test number 9 the authors want to see what effect this phenomenon can have on the results. The relative error is the highest in the cases where extremely low volumes are handled. Test nine is a such case. What will happen when only one unit can be produced each week but the forecast is three units is that the production split will be 33.3 %, 33.3 % and 33.3 % for each model. 33.3 % of 1 unit equals 0.333 units, which when rounded gives 0. Therefore, no units at all will be produced in this case. This phenomenon can be viewed in Figure 105 and Figure 106. In the buffer inventory, the volume levels steady increase since nothing leaves and the FGI steady decreases until it reaches zero.

<table>
<thead>
<tr>
<th>Test Data Set 9</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Forecast Model C</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Order Model C</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
<th>Status Model C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
This phenomenon does not necessarily only occur for small values. Another combination that can generate this is when a simulation of many models is done, the forecast is the same for all these models and the capacity limitation in the production compared to the total forecasted volumes is quite small. However, this seems to be a quite unrealistic case since the productions hopefully adapt the capacity after the demand.

In the tenth test a combination of high and low values was tested. The settings are presented in Table 49. The test data set is characterised by a high-volume Model A and a low-volume Model B. These are shown in Table 50. In this case, the first split that is computed is 250 divided by 251 and 1 divided by 251, which results in 99.6 % and 0.4 %. But since the buffer inventory only has 50 units of Model A available a new split will be computed which will be 50 divided by 51 and 1 divided by 51. This results in 98 % and 2 %, which gives 49 units and 1 unit respectively. The simulation model
handles this case correctly and 49 units of Model A and 1 unit of Model B are produced each week, which is visualised in Figure 107 and Figure 108.

Table 49. Settings for Test 10

<table>
<thead>
<tr>
<th>Test Data Set 10</th>
<th>Forecast Model A</th>
<th>Forecast Model B</th>
<th>Order Model A</th>
<th>Order Model B</th>
<th>Market Allocation</th>
<th>Status Model A</th>
<th>Status Model B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1-30</td>
<td>250</td>
<td>1</td>
<td>50</td>
<td>1</td>
<td>51</td>
<td>50</td>
<td>1</td>
</tr>
</tbody>
</table>

![Buffer Inventory](image)

Figure 107. Test 10 – Buffer Inventory
Figure 108. Test 10 – FGI