Master's Thesis
ISRN LUTMDN/TMFL–12/5098–SE

Simulation of Finished Goods Inventory

– Next Step Towards Factory Simulation

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-Next step towards Factory Simulation

Packaging Logistics

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Division of Packaging Logistics

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Preface

This Master Thesis has been written during the spring of 2012. The thesis is collaboration between the packaging Company and Lund University. First of all, we would like to thank our supervisor Mr. Carl-Magnus Bertilsson, Manager Virtual Engineering Department, for giving the opportunity to write a Master Thesis at his department and all the support he has given us during the thesis. We would also like to thank Mr. Haris Omeragic and Mr. Sebastian Ferrada, Simulation Engineers at Virtual Engineering Department. You have truly helped us with answers to all our questions and constructive feedback to our ideas. We would also like to thank Assistant Professor Daniel Hellström at Division of Packaging Logistics, Lund University, for his support and true interest in our thesis. You are a true inspiration to us! Finally, we would like to thank all of you we have not mentioned but who have been supporting and helping us to write this thesis in one way or another. You have contributed to making this thesis the most fun project during our five year Master's program in Mechanical Engineering.

Marcus Sandström & Daniel Zulumovski

Lund, June 2012

Abstract

Title: Simulation of Finished Goods Inventory
-Next step towards Factory Simulation

Authors: Marcus Sandström & Daniel Zulumovski

Supervisors: Asst. Professor Daniel Hellström, Lund University
Mr. Carl-Magnus Bertilsson, Manager at the Virtual Engineering Department, Company

Purpose: This Master Thesis has the purpose of creating a simulation model of a finished goods inventory at one of the Company's factories. In addition, an improved layout should be proposed.

Design/Approach: A simulation study using discrete-event simulation has been performed in the recommended steps by various literatures. A thorough study was made to identify the stakeholders and the relevant requirements set on the finished goods inventory.

Originality/Value: The Company has adapted a long term strategy regarding the usage of virtual engineering to stay competitive and remain as market leaders. The model of the finished goods inventory will be an important part of a detailed factory simulation. The model should also be used to evaluate different layouts in the finished goods inventory to find improvements. The improvements will hopefully reduce the life-cycle cost of the packaging material which is produced in the factory.

Limitations: The Master Thesis is only focusing on the Finished Goods Inventory in Arganda, Spain. Only the finished goods of packaging material are taken into consideration.

Findings: A simulation model has been created which is fully compatible with a factory simulation model. In addition an improved layout of the FGI has been presented. If the layout is implemented, the annual life-cycle cost of the packaging material will be reduced with 43000€.

Keywords: Discrete-event Simulation, Logistics, Production, Scenarios, Warehouse

Sammanfattning

Titel:	Simulering av Färdigvarulager -Nästa steg mot Fabrikssimulering
Författare:	Marcus Sandström & Daniel Zulumovski
Handledare:	Lektor Daniel Hellström, Förpackningslogistik, Lunds Universitet Carl-Magnus Bertilsson, Manager för Virtual Engineering, Företag

Företag levererar ett helhetskoncept till sina kunder. De tillverkar alla komponenter för processering av flytande livsmedel så som fyllningsmaskiner, transportband, förpackningsmaterial m.m. Företaget har antagit en långsiktig strategi för användandet av virtuell teknik som tros vara ett led i att kunna fortsätta vara konkurrenskraftiga och behålla sin position som marknadsledande. Ett första steg i denna strategi är att skapa ett bibliotek av simuleringsmodeller för de olika aktiviteterna för fabriker som tillverkar förpackningsmaterialet. När det väl är gjort, kan modellerna kopplas ihop till en enda modell, en fabriksmodell. Med hjälp av en fabriksmodell, kan hela flödet analyseras, från råvara till färdigt förpackningsmaterial. Genom att se hela flödet, kan flaskhalsar identifieras och då även åtgärdas. Genom att simulera hela fabriken undviks också s.k. suboptimering. Suboptimering innebär att en del av fabriksaktiviteternas prestanda förbättras vilket leder till att andra fabriksaktiviteters prestanda försämras. Målet är att ha kopplat ihop den första fabriksmodellen i slutet av 2012 för Företagets fabrik i Arganda. När fabriksmodellen är klar, är det meningen att fabrikerna själva ska kunna utföra experiment med olika scenario för att se hur hela fabriken påverkas och vilka kostnader som uppstår. Företaget vill på så sätt minimera kostnaderna som läggs på förpackningsmaterialet, den s.k. livscykelkostnaden. Det långsiktiga målet i strategin är att alla fabriker ska ha en fabriksmodell vid slutet av 2017.

Nästa steg för att nå målet med en första fabrikssimulering, är att skapa en modell av färdigvarulagret i fabriken i Arganda. Modellen ska också användas för att kunna utvärdera olika planlösningar och materialhanteringsaktiviteter. Då kan eventuella förbättringsmöjligheter finnas som kan sänka livscykelkostnaden för förpackningsmaterialet som tillverkas i fabriken. Examensarbetet fokuserar endast på fabriken i Arganda, Spanien och begränsas till färdigvarulagret. Enbart det producerade förpackningsmaterialet tas i beaktning vi utleverans från färdigvarulagret.

Metodiken som har använts baseras på rekommenderade steg i en simuleringsstudie. Relevanta processer i flödet av färdiga pallar med förpackningsmaterial från fabrik till färdigvarulager och vidare ut till kund har kartlagts. Intressenter har identifierats och relevanta krav som ställs på lagret har också skapats ur tolkningar från intressenternas behov. När en lista på alla krav har blivit verifierade av intressenterna, har en simuleringsmodell skapas av färdigvarulagret. Modellen är helt kompatibel med en fabrikssimulering. En rad experiment har utförts på olika scenarios där olika parametrar ändras. Experimenten resulterade i en rekommendation på ny planlösning där ytterligare en lastzon installeras. Vid ett eventuellt genomförande av den nya planlösningen, kan livscykelkostnaden minskas med 43000€ årligen.

Abbreviations

AGV – Automated Guided Vehicle

AS/RS – Automated Storage and Retrieval System

ATA – Actual Time of Arrival

BMI – Base Material Inventory

COP – Customer Order Point

DC – Distribution Centre

ETD – Estimated Time of Dispatch

FGI – Finished Goods Inventory

FIFO – First In First Out

FILO – First In Last Out

HC – Holding Cost

KPI – Key Performance Indicator

MTBF – Mean Time Between Failures

RC – Relocation Cost

SKU – Stock Keeping Unit

VMI – Vendor Managed Inventory

WIP – Work-In-Progress

WMS – Warehouse Management System

Table of Contents

1. Introduction

A brief presentation will be given of the background, problem and purpose of the Master Thesis. The Company will be described as well as which target group the report is aiming towards.

1.1 Background

By using a more holistic approach, companies can improve their way of developing the organization. Like most other companies, Company work continuously to improve their business to become as profitable, competitive and effective as possible. Initiatives have been made to increase focus on having a system approach in development projects. By looking at the entire system and then breaking it down to sub-systems, it is possible to identify all the requirements that are necessary for each sub-system and how it interacts with other sub-systems.

Systems Engineering works continuously with identification and understanding of needs and requirements that each activity has in a converting factory, which is where the packaging material is produced. To get an in-depth understanding of the Company's converting factories, line simulations have been performed. These are simulations for specific activities in the converting factory e.g. printing station or lamination station. The line-simulations visualize possible bottlenecks and are a very helpful support when developing optimal solutions regarding cost, efficiency, waste etc. By extending the line simulations to a detailed factory simulation, it is possible to understand how each part of the system is affected by each other if there is a sudden change in the system e.g. malfunctions or high priority order. The goal is to have one complete factory model by the end of year 2012 and a model for each factory by the end of year 2017.

The work according to the long term strategy is currently in the starting phase. The models will be part of a library of simulation models that can be used for future factory simulations. This will be possible since there are similarities between the factories. The final outcome would be that the factories can run the simulation model simultaneously as the production to evaluate how the production will be affected by a change of order and if it will be profitable to the Company to make that change. A first pilot factory has been chosen to work closely with, which is the factory in Arganda, Spain. At the pilot factory, there have been a few projects where simulation models of the different sub-systems have been created. These projects have mainly been focusing on line simulation. The next step is to focus on the material handling to eventually complete the first factory simulation.

1.2 Problem Discussion

By simulating the Finished Goods Inventory (FGI), improved layout can be found with respect to the life-cycle cost. As part of the project of creating a complete factory simulation, models of each step in the material handling must be built. The main activities regarding the material handling are the Base Material Inventory (BMI), Work-In-Progress (WIP) and FGI. The BMI has a low complexity due to the low number of material qualities handled and large batches ordered. FGI has a significantly higher complexity due to each order is customized, which makes it more suitable for a simulation study. Furthermore, the products in the FGI have been refined and have therefore a higher value for both the Company as well as their customers. In addition to just creating a model as part of the factory simulation, it is also interesting to evaluate the life cycle cost of the packaging material. By improving the layout of the FGI to minimize the cost for the overall performance of the factory, the minimum life-cycle cost can be found. Different layouts of the FGI can be tested in the simulation model to improve e.g. space utilization, travel distance and put away-policy. By doing so, it will be possible to identify the best layout regarding the life cycle cost. The requirements of the material handling in the factory must be well identified to be able to create a realistic model of the FGI.

1.3 Purpose

The purpose of the master thesis is to create a simulation model of the FGI which can be used as a part of the factory simulation of Arganda. Furthermore, the model should also be a part of a model library so it can be used in future factory simulations. Three key objectives have been set:

1. To identify and define relevant requirements within the FGI.
2. To define a simulation model with respect to the life-cycle-cost of the packaging material, for the Company's factory in Arganda. The model will also be used in order to compare the current layout with other layouts in the FGI.
3. To propose, from a life-cycle-cost point of view, an improved layout and material handling setup in the FGI that fulfils the requirements.

1.4 Focus and Limitations

The study is focusing on the Arganda factory in Spain hence to its ongoing pilot project. Regarding the factory processes, the study will only focus on the FGI. The FGI is a part of a warehouse in the factory. In Figure 1, the FGI is positioned in the distribution part of the factory chain.

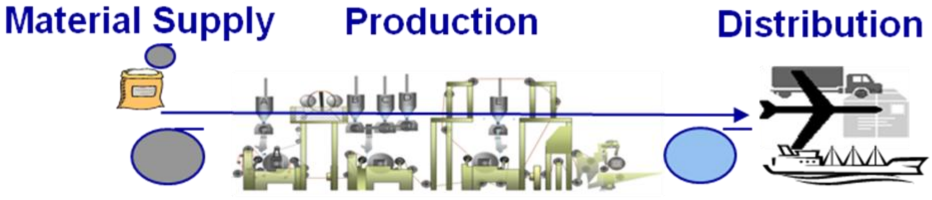

Figure 1: Company Factory Chain

There are additional goods shipped with the packaging material. The additional goods are stored in a separate location and are not produced in the factory. Therefore, only the finished goods arriving from the factory will be taken into consideration. Shipments transported directly from the FGI to the customers or to an external warehouse will be taken into consideration. The stakeholders involved in the thesis are limited to the forklift drivers, the forwarders and the warehouse management.

1.5 Company Description

The founder of Company was first introduced to pre-packed goods during his studies in the U.S.A in the late 1910's. He saw Sweden as a potential market and decided to start a new company together with his business partner, focusing on packaging. The company grew rapidly and soon the food processing industry was identified as a potential customer. The founder decided to start a new company mainly focusing on food packaging, so in 1951 Company was founded in Lund, Sweden. The packaging products are carton based and are coated and laminated with aluminum and/or polymer or to protect the product. The packaging material is then delivered the customers who have the Company's filling and processing equipment. The founder once said "a package should save more than it costs" and the mantra has become an integrated part of the business. By offering a practical, cheap and safe package to its customers has lead to Company becoming the world's leading food processing and packaging solutions company. They provide its customers everything needed for processing, filling and distribute food and beverage. Today, Company operates in more than 170 countries with over 20,000 employees.

1.6 Target Group

The master thesis is in firsthand relevant for the Virtual Engineering Group at Company as part of their work in Factory Simulations. The thesis is also highly relevant for people involved in warehousing strategies due to the improvement of the FGI. It could also be valuable for industries which are interested in Factory Simulations but are uncertain of how to start as well as what kind of result to expect. Finally, the thesis can act as a guideline and inspiration to students who are interested in warehousing strategies in combination with discrete-event simulation.

1.7 Outline of Report

This report is divided into the following chapters:

1. **Introduction**
   In the introduction, the background and purpose of the thesis is presented. The company is briefly presented and limitations of the thesis are established. Finally, the Target Group for the report is presented as well as the outline of the thesis.

2. **Methodology**
   The main methodologies of the study are presented. The main methodology for analyzing the FGI is by using *Discrete-Event Simulation*. In Discrete –Event Simulation, a computer model of the system is created in which different event can be simulated to analyze the system as it is and/or different scenarios for the system. These methodologies will act as guidelines throughout the study. In this chapter it will also be clarified how different requirements of the system was gathered through interviews and how they are presented in a system description.

3. **Frame of Reference**
   In this chapter, the knowledge which is referred to in the study is presented. The knowledge has been found in different sources of literature, mainly books and scientific articles. *Logistics, Warehousing* and *Life-Cycle Cost* are the key knowledge which have been used and will be explained thoroughly. The chapter will help the reader to understand how the empirical results have been obtained, how conclusions have been made and what the conclusions are based upon.

4. **Finished Goods Inventory Description**
   A detailed description of the FGI and all the activities involved will be formed were the system limitations will be more thoroughly established. By analyzing each stakeholder needs together with a deep understanding of how each process in the system is performed, the requirements for the FGI can be identified. By performing interviews, work-shops and observations of the stakeholder needs will be formulated into system requirements which will act as a part of the input data in the simulation model.

5. **Simulation Model**
   In this chapter, the structure of the simulation model will be presented. The result of the validation of the model will be given. Thereafter the experimental design will be presented in the form of different scenarios with the purpose to optimize the FGI.

6. **Results & Discussion**
   The final results from the experiments will be presented. Each scenario will be analyzed in detailed discussions regarding the credibility as well as feasibility. The cost for each scenario will also be evaluated.

7. **Recommendations & Conclusion**
   The scenario which contributes to the most beneficial improvement and largest saving with respect to the life-cycle cost will be presented. A conclusion regarding the purpose and objectives will be given and recommendations for further research.

2. Methodology

In this chapter, a thorough explanation of the methodology which has been used in the study is presented. The main methodology for the study involves simulation, identifying the system requirements and the necessary steps included to reach a successful end result.

2.1 Simulation

Simulation is problem-solving method (Banks, 2000,) which is very useful when the systems become so complex that common sense and simple calculations are not enough. The purpose of the simulation models is to provide the observer with enough information that the behaviour of the simulated system will appear and be as similar to the real system as possible (Banks et al, 1996; Cassandras and Lafortune 2008; Law and Kelton, 2000).

2.1.1 Introduction to simulation

In modern times, the different systems of an organisation can be really hard to understand and the correlation between different processes can be difficult to distinguish. The foundation of this simulation study is based on the input data from the original system that is to be simulated. The input data is used when designing the simulation model, which means that the reliability of the simulation model is based on the input data. That is why in a simulation project, the accuracy of the pre-studies becomes extremely important (Banks et al, 1996).

A simulation model in a virtual environment does not affect the real system when evaluating the different scenarios. That is why it also is effective from an economical point of view. Simulations are often used if the system has unpredictable parameters that randomly will change over time. Then a simulation model probably is the best way for creating a realistic model, or to just create an understanding for a complex system (Trilogic Konsult 2008).

2.1.2 Model types

Models can be structured into different layers, which will indicate what type of model which is the most appropriate for each simulation. The first layer is stochastic and deterministic. A stochastic model is a model that is based on that random element will occur. A deterministic model is a model that contains no randomly elements. The model of the FGI will include random elements and because of that a stochastic model is most appropriate for the model. The second layer is whether it is static or dynamic. A static model describes an average due to a specific time, while a dynamic model will observe the behaviour of a system over time. The behaviour of the FGI will wary over time and due to the variation, a dynamic model will be necessary. The third layer is if a model is continuous or discrete. Discrete means that events can occur at a discrete set of points in time which is the opposite of the continuous system (Banks et al,1996). The events in the FGI will occur at a specific time, which make the discrete-event model most suitable for the FGI in Arganda. The model taxonomy can be seen in Figure 2.

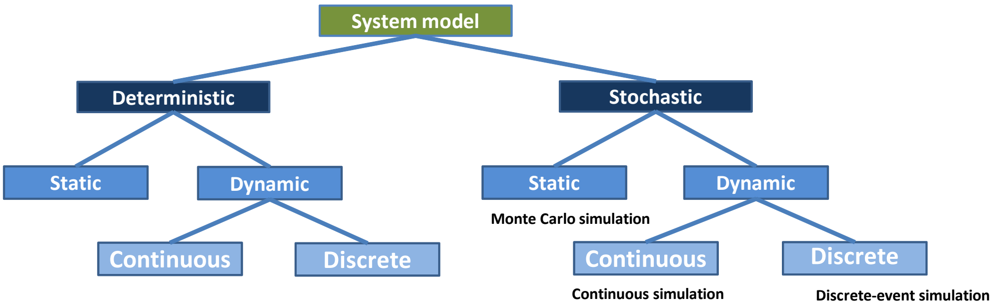

Figure 2: Model Taxonomy (Park and Leemis, 2012)

Explanations of stochastic models according to Richard Nance:

Monte Carlo simulation: The name comes from its similarity to gambling strategies. It utilizes models of uncertainties where representation of time is not needed. It relies on repeated stochastic sampling to compute the results. A Monte Carlo model is most used in computer simulations of mathematical and physical systems.

Continuous simulation: Is a simulation models that are based on equations. These types of studies do not require that the explicit state and time has a certain relationship, which could lead to discontinuities in the result. Continuous simulations are often used in large-scale economic modelling. That is why the continuous simulation model not is used.

Discrete-event simulation: Simulation is a reproduction of a process or a system in the real world over time (Banks et al,1996). The model utilizes a mathematical and logical approach. The discrete-event simulation is based on parameters that are stochastic and could change at any time and therefore affect the whole system randomly (Banks et al, 1996). It is almost impossible to create a discrete-event simulation model that has the exact precision as the real system due to the dynamic in the real world. By using simulation it will be possible to answer different types of questions like" what if" and "is it possible" (Banks, 2000; Banks et al,1996). Due to its possibility to take the dynamic in consideration, a discrete event simulation is the best alternative for the thesis. Many parameters in the FGI are stochastic and will change over time.

2.1.3 Applications of simulation

In the thesis, a discrete-event simulation model has been used. Simulation is very suitable for industrial use, which suited this thesis. Simulation is very useful if the need is to evaluate the performing level of a specific process which this thesis intended to do (Law and Kelton, 2000). The simulation does not have to stop the FGI in case of testing a new layout. Because of that, it will suit this thesis very good. Referring to Banks (1998), it is possible to apply simulation if one of the suggestions below is wanted.

Applications due to manufacturing and material handling:

- Minimizing delays of prefabricated parts before assembling.
- Evaluating Automated Guided Vehicle (AGV) routing tactic.
- Modelling and analyzing large-scale Automated Storage & Retrieval (AS/RS)-systems
- Design and analysis of large-scale material handling systems.
- Estimate the cost of quality.

Due to its possibility to design and analyze material handling system, simulation will be very appropriate for this thesis.

2.1.4 Advantages and disadvantages of Simulation

If the simulation is done correctly, advantages can be obtained (Banks, 2000). The thesis had the vision to gain advantages by simulate the given problem and avoid the disadvantages. The authors have been aware of the disadvantages and have taken them into consideration. By basing the simulation strategy on a model established by Banks, the chances for obtain the advantages will increase (Banks, 1998). During the thesis, the following advantages have been obtained:

Different Scenarios: Simulation enables the possibility to test the different scenarios that have been chosen to be evaluated. Simulation allows a system to be tested without committing resources to it.

Compress and expand time: Simulation has allowed speeding up or slowing down different sequences so they can be investigated carefully.

Understand why: Managers often have many questions about how thing really works or why some specific events occur. When the model was shown to the managers, the simulation model gave the opportunity for them to analyse the desired case more thoroughly.

Develop understanding: Many people operate in the FGI within the trust of each other capability of understanding the system. The simulation model showed how the correlation between how everything really works for those involved in the FGI.

Prepare for change: In the future, there have been thoughts about improving the layout of the FGI. The simulation model will give approximate answers to the layout that has been discussed.

Specify requirements: Simulation can be used to define requirements for a specific system if needed. The approach has been to identify relevant requirements for the FGI. Some of the requirements have been identified by developing the simulation model.

But there has of course been had some disadvantages as well:

Model building requires special training: Company is using a simulation software that the authors never had been in contact with before. Because of this, it has been very time consuming to learn a new simulation software from the beginning.

Simulation result may be difficult to interpret: Some simulation results have not been as expected. It has been hard to determine whether an observation is a result of the interrelations of the system, or because of randomness regarding the length of a simulation run.

2.1.5 Steps in a Simulation Study

According to Banks, a simulation study should be divided into certain steps. Figure 3Figure 3: Bank's Model (Banks et al, 1996) shows the different steps, how they should be applied and how they are connected to each other. By following these steps, the chance of success in a simulation project will increase (Banks, 1998).

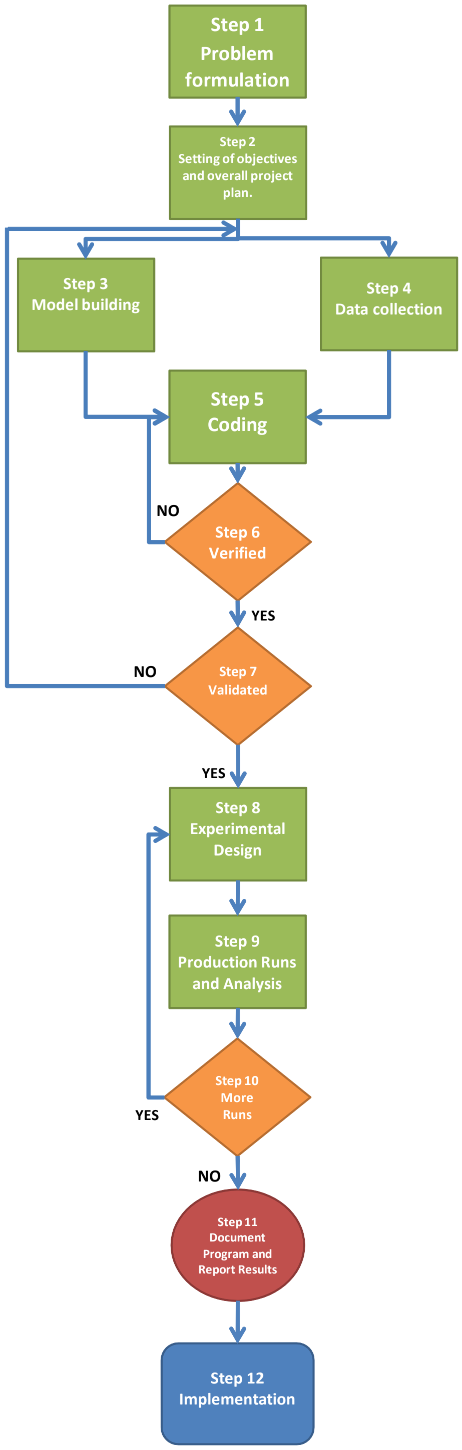

Figure 3: Bank's Model (Banks et al, 1996)

2.2 Simulation study

The thesis is based on the Banks model for simulation. The model is a common methodology for simulation studies. It is generally used in the industrial area, due to successful delivery of strong and accurate results (Banks, 2000). Banks model uses many steps, so the user of this methodology can easily go back and change things if it is not satisfying (Banks et al, 1996). This thesis has not followed the Banks model exactly, but mainly. Some steps are not necessary for this thesis and others have been of greater importance.

2.2.1 Problem Formulation

In the starting phase of the thesis, the authors were given a task to solve for Company. The task was to improve some parameters in the FGI in Arganda which should reduce the life-cycle cost of the packaging material. The task was discussed to clarify the objectives. The task that was given needed a simulation study to obtain an accurate result that Company had required. The purpose for the thesis was identified.

2.2.2 Setting the objectives and overall project plan

In the beginning of the thesis, it was necessary to get a structure of what was needed to be done and how it should be done. All the objectives were set, which means that Company informed what they want and expects from the simulation project. A project plan was established which describes how the work would be accomplished and with what type of resources that was be needed. The project plan also includes a detailed time plan.

2.2.3 System understanding

During this phase, the simulation model was built. The aim should be to imitate the real system as much as possible. The model is illustrated by a conceptual model. To be able to create an accurate conceptual model, the input is mostly based on a system description. A good strategy is to start with a rough model and then step by step improve it along the process when additional information is gathered. Company has been involved in the modelling process, the developing of the system description and all relevant requirements which were identified. Company were aware of how the work was done and how it proceeded. That increased the quality of the study and the stakeholders' confidence in the model.

The purpose of the system description is to represent the structure of a system in a detailed way (Banks, 2000). The system description shall be able to explain for uninvolved people who don't know about the system and make them understand how the whole system works. The system description shall include relevant information to minimize time consuming loops with questions regarding the system. It is important that the language in the system description is understandable for all stakeholders who may have an interest of reading and verifying it. The system description should also include all steps in the process that are observed. It should also clearly show how the different elements are connected and depending on one another (Ingalls, 2002).

A system description should include if possible the content of Table 1.

• Events	• Regulations	• Distance
• Administration	• Limitations	• Times
• Connections	• Areas	• Layouts
• Capacity	• Hand-overs	• Handling
• Conditions	• Dimensions	• Equipment
• Phases	• Products	
• Flows	• Employees	

Table 1: System Description Contents

Since the thesis is written in Lund, Sweden, there are some geographical difficulties to take in consideration. To be as prepared as possible for the visit in Arganda, a pilot study has been made at the Company FGI in Lund due to the similarity of the FGIs. Interviews have been made with the Warehouse Manager, Supply Chain Manager as well as to the Factory Design & Logistics team, to gather as much information as possible. By doing so, a set of questions have been created for the purpose of understanding the FGI in Arganda in detail. See Appendix I for pilot study.

2.2.4 Data collection

Two visits in the Arganda factory were essential to be able to collect raw data from the FGI, identify the stakeholders and their needs. Each stakeholder influencing the system must be identified as well as which level of involvement they have. Stakeholders defines a as *an individual, group of people, organisation or other entity* *that has a direct or indirect interest (or stake) in a system* (Hull et. al, 2011, p7). The different levels of involvement of the stakeholders in a development project are shown in Figure 4.

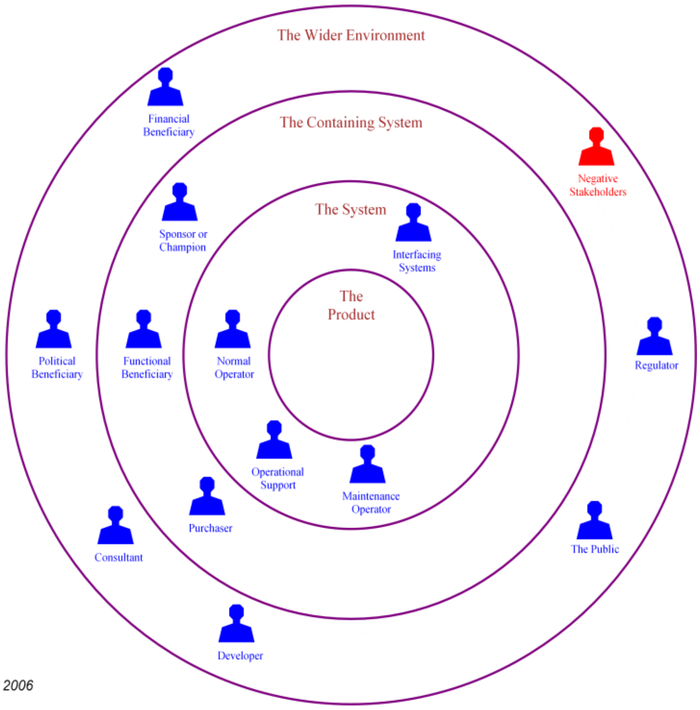

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Figure 4: Onion Model Stakeholders (Alexander 2006)

The Data has been collected during the visits to Arganda, in form of interviews, workshops and observations. Before each visit, questions have been prepared regarding to how the system works. With the answers to the questions, a relevant model of the FGI was built.

Interview is most likely the most frequent way to identify the stakeholders needs (Alexander and Beus-Dukic, 2009). An interview is when one or more persons ask other persons question to get information from these persons regarding a certain area. It is a powerful tool if it is used correctly, but of course it has its disadvantages. If it is a very complex process, then only interviews is probably not the right way to go. An interview requires both skills and planning to reach the main purpose of the interview (Sallnäs, 2012). The authors do not have any special interviewing skills, but they have made the decision, that this technique to collect needs and requirements will have enough accuracy.

Interviews are best performed if there are two interviewers (Alexander and Beus-Dukic, 2009), and a follow-up interview is also recommended. During the thesis, there have been many follow-up interviews. Because of the complexity of the system, it is natural that additional questions will appear during the thesis when the knowledge of the system increases. Therefore, follow-up interviews are very common and helpful. Figure 5 shows the process for identifying requirements, starting at interviewing the stakeholders.

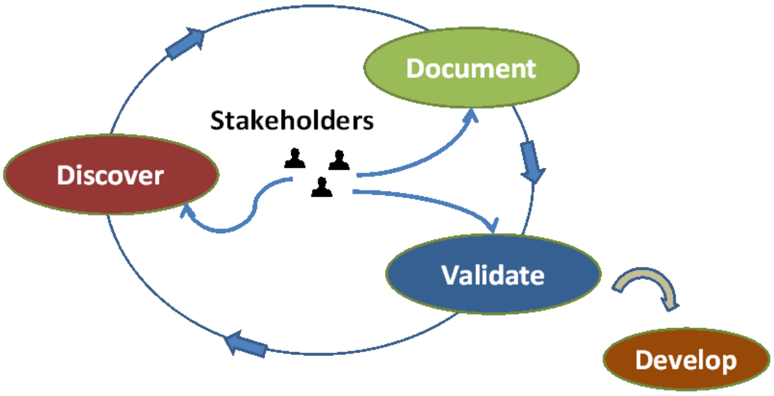

Figure 5: Inquiry cycle for creating requirements (Alexander and Beus-Dukic, 2009)

Workshops can be very useful in a project. In workshops, it is possible to introduce different stakeholders to each other, to make them work towards a common goal (Alexander and Beus-Dukic, 2009). It is also possible to look at a problem or system from different angles, when there is more than one person describing the system. Different stakeholders of the FGI were invited and different questions were asked and they also had a discussion to identify different needs and requirements. Different scenarios for experiments and some complex requirements were identified during these workshops. There are many advantages to obtain by using interviews and workshops when collecting data (Sallnäs, 2012; Alexander and Beus-Dukic, 2009). The advantages obtained during the thesis where:

Engaging with stakeholders: Personal attention was given to each stakeholder during the interviews. By having a friendly approach, it is possible to gain much more from an interview and get good cooperation.

Dialogue and feedback: It was possible to get feedback on the work that had been done so far and having a dialogue of possible changes in the model and scenarios for experiments.

Follow-up: By having the possibility to do a follow-up interview, the opportunity to confirm that the work that was done had some accuracy was given. Additional questions that had come up during the thesis could also be asked and answered.

Once the stakeholders' needs and constraints have been discovered, they can be translated into system requirements. The requirements are often expressed as "system shall" (Alexander and Beus-Dukic, 2009). For example, a customer explains his need by saying, "We cannot fit any pallets into our racks if they are higher than 1.7m." The requirement would then be "the pallets shall have a maximum height of 1.7m". See Appendix II II for a detailed description of the translation from needs to requirements set on the FGI in Arganda.

The data has been collected during the visits to the Arganda factory. However, additional data has been sent by email and some questions were answered by telephone. The goal for the collection of the input data has been to use as much raw data from the Arganda factory as possible. However, not all raw data that was needed for the model could be collected. Instead, the data for the arriving goods have been generated from the simulation model built for the Finishing Area. This data is only based on a single run of that model.

2.2.5 Conceptual model

Once the system description and the requirements have been verified, the relevant information can be applied in a simulation model. The first step is to clarify the level of detail of the FGI which should be simulated. A too detailed model of the FGI has more variables and demands more work-hours to complete. A too low level of detail will leads to a simplified simulation of the real system, with a high risk of losing valuable input. The conceptual model for Arganda is based on the system description and will be the base while coding the model.

2.2.6 Coding

Once the conceptual model was created, it was possible to begin to build the model to be like the conceptual model. The coding has been a large part of the thesis due to the new software that has been necessary to learn and to the complexity of the system. The authors has been coding together to minimize the errors in the code and to both get an understanding of how the model works and both to learn the new software.

2.2.7 Verification

When the different stakeholders needs have been identified and translated into system requirements, a scenario can be created. A scenario is a step-by-step process of the system (Alexander and Beus-Dukic, 2009). By taking the stakeholder through the scenario, each step and its requirements can be verified. The stakeholder will then be able to see if there are any steps missing, steps in the wrong order or any misunderstandings regarding the requirements (Alexander and Beus-Dukic, 2009). Verification of the model is very important step to assure that the conceptual model is reflected as accurate as possible in the simulation model (Banks, 1998).This model has been verified by the system experts who have a good understanding of how the system should work. It was also verified by the authors who have created the model and has gained necessary knowledge about the system. There has also been a requirement list made for the system specialists in Arganda to verify. For example each requirement has been discussed and evaluated with the specific requirement specialists. They were also given the opportunity to verify the model by looking at the model and come with suggestion and feedback that has been taken in consideration. This method is used to get as good verification as possible. The following steps have been taken to verify the model:

1. The logic code has been checked by the authors as well as by a Simulation Engineer (Omeragic, 2012).
2. A detailed flow chart has been made of the different activities (Figure 38, Figure 39) to simplify the model building and the creation of model logic.
3. Logic errors have been found and fixed by using *Debugger*[1].
4. Self-documentation of the model has been used. Each variable have been given a logic definition. For example, the forklifts are called forklift1 forklift2 etc. Each part of the logic code is described in detail in case of further improvements by other developers in the future.
5. The visual representation of the model looks and act like the system in reality when it runs. The Storage Keeping Units (SKUs) are placed properly and the forklifts acts as they should etc.
6. Response of the model and response data from reality has been compared to see if the model gives reasonable results.
7. Model requirements have been verified by a system specialist (Escrich, 2012). A detailed "walkthrough" of the simulation model where each

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[1] A Debugger, or *Interactive Run Controller*, is a tool to stop the logic code at a specific event in an object to analyze errors (Banks et al, 1996)

identified requirement was presented, act as a final guarantee that the model is verified. See Appendix II for example of requirements verification.

2.2.8 Validation

Once the model has been created and all the model requirements have been implemented in the model, simulations will be possible. The original model has to be verified and validated before any experiments can be performed. The model have to be calibrated to match the real output and behavior. The best way of validating the model, is to compare the input and response from the model to the input and response from the real system (Banks et al, 1996). But there are other ways to validate the model. Face validation is to show the model to system experts and get the opinion that the model has high realism, (Park och Leemis, 2012) and have the same behaviour as the real system. A Turing test can also be done to validate. The validation of the model is the last step before experiments can be performed. The validation will add credibility to the final results since it will guarantee that the model behaves as the real system (Banks, 2000). *" An approximate answer to the right problem is worth a good deal more than an exact answer to an approximate problem"*(Tukey, 2012, p.1). The validation can be made in numerous ways**.** For this model, the historical data test has not been done, due to failure to collect matching input and output data for the FGI. Instead a face validation has been done and validation of model assumptions has been discussed.

Face Validation: The model has been shown for the Warehouse Management and all the model assumptions thoroughly explained. The Warehouse Management has ensured that the behavior of the model reflects the reality to level that the results can be seen as credible.

Turing test: The model output and the real system output have been compared. Seven days of throughput from the model is compared with seven days of throughout from the real system. Since the input data used in the model is based on the dates: January 3rd - January 10th, the very same date are used for the data for the real system. Below shows the throughput of the model vs. the real system

Extreme Condition Test: An extreme condition test was done to see if the response of the model would change by removing the limitations in the model such as arrival frequency of the picking lists, loading time breaks etc. The frequency of the arriving SKUs will remain the same as in the original model.

2.2.9 Experimental Design

Experimental Design is to test the model by changing parameters to get different outputs and views. To be able to find an improved layout of the FGI, different scenarios for possible improvements have been created. Once the simulation model has been verified, it can easily be modified to fit the scenarios where the possible improvements are included. For each scenario that is designed, there are some factors that have to be considered. The simulation over FGI in Arganda will evaluate the performance parameters.

Total throughput for each day: The total throughput is the total amount of SKUs that has entered the system and leaved it by being shipped each day.

Number of relocations: The total number of times a SKU has been relocated to be able to pick another pallet.

Average stay time: The average stay time SKUs is stored in the warehouse before it leaves the system.

Forklift average total distance: The average distance for a forklift during the wanted period. The average distance is only connected to the picking forklifts due to relocation is a sub-activity to picking, and that picking is the biggest activity in a warehouse (Frazelle, 2002).

Input: Number of SKUs that enters the warehouse.

Average inventory level: The amount of SKUs that is stored in the warehouse at the beginning of each day.

2.2.10 Documentation and Results

Documentation is very important. The documentation started from the beginning of the thesis and has almost been ongoing throughout the whole time except for a part when all the focus was on the coding of the model. There have been times along the thesis when necessary data was not delivered. Through these times, the focus was on the documentation, to be able to go back later and check what have been done and how it was done. This has increased the quality of the thesis.

2.3 Simulation Software

Since the FGI in Arganda is complex system due to its dynamic. Stochastic events occur and analytical analysis will be extremely difficult and tedious to perform. By building a model of the real world in simulation software, a solution can easily be obtained by using numerical analysis (Banks et al,1996).

Company is currently using software named FlexSim. It is a discrete-event simulation program based on C++ program language that observe the behaviour and dynamics of the system, and creates statistics that easily can be evaluated. Therefore, the model of the FGI in Arganda will be built and analyzed by using this software. The discrete-event simulation model is the type of model that will fit this project best, due to the complexity of the FGI. There are many parameters in the FGI which are stochastic and could have a big impact on the system. Another reason for using FlexSim is to be able to adapt to the earlier simulation models which have been done in this software for other parts of the factory. Eventually, it will be possible to simulate a whole factory by connecting different sub-models.

The authors have never used FlexSim before and are therefore forced to learn a new software from scratch. This has been done by doing tutorial exercises in the starting phase, to get a basic understanding of how the new software works and later on learning by doing. Help has also been given from colleagues at Company which have the right knowledge regarding this software. In the end of the thesis, the authors have gained much knowledge of this software that could be useful in future projects.

3. Frame of Reference

This chapter explains all the knowledge found in literature which will be used in the study. The main areas which are used in the study are; Logistics, Warehousing and Life-Cycle Cost.

3.1 Logistics

Logistics is today an essential part of the long term strategy of a vast majority of companies. Logistics is a part of the supply chain in an organization. The world´s leading source for the supply chain profession, Council of Supply Chain Management Professionals, defines logistics as follows:

"Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses 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." (CSCMP, 2012)

This definition clearly shows that it is the customers' demand that should be used when deciding which logistic strategy to use. The goal of Logistics is basically that all customers should get the wanted products at the right place, at the right time to a low cost (Oscarsson et al, 2006). A product is sometimes handled by many different companies in a logistics flow; producers, forwarders, distribution centres and so on until it finally reaches the end consumer. Each step in the flow has a cost (Stock and Lambert, 2001). Therefore, it is important to be as cost effective as possible throughout the logistics flow. The main trade-off in Logistics is combining a low cost and a high service level to the customers (Oscarsson et al, 2006). If a company manages to find an optimal combination, it will have an advantage towards its competitors. This can only be achieved by having a well coordinated information flow (Hompel and Schmidt, 2007).

3.1.1 Logistics in a Producing Company

A general conception of a producing company is that it consists of three main logistics parts (Oscarsson et al, 2006): Material Supply, Production and Distribution, see Figure 6. The Throughput Time is the time from receiving the raw material to the delivery to customer. The Lead time is the time from Customer Order Point (COP) until delivery (Oscarsson et al, 2006). Between each part there are usually three repeating activities; transport, materials handling and storage (Oscarsson et al, 2006).

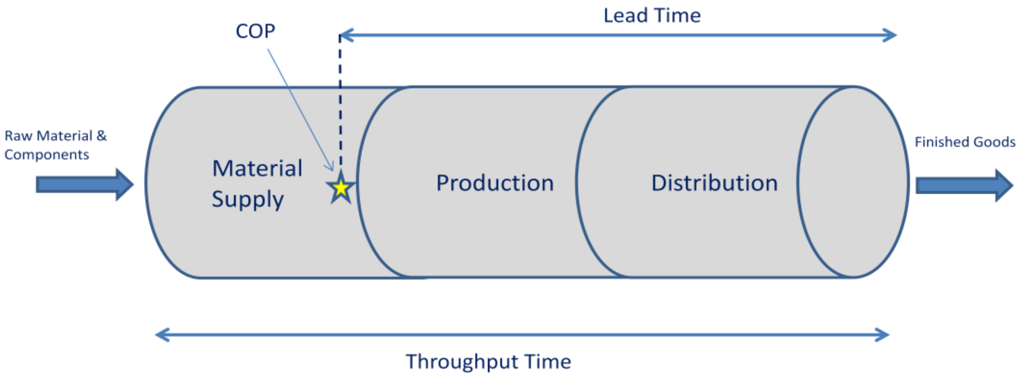

Figure 6: Logistics pipe (Oscarsson et al, 2006)

Depending on which order policy the company has, the COP could be placed differently in the Logistics pipe. The policy could either be make-to-order, make-to-stock or a combination between the two policies. The make-to-order policy offers a customized production with small batches and longer lead times. This policy can only be used if the customer is ready to wait for the product being made. The make-to-stock policy requires larger batches of a standardized product and provides a short lead time for the customer. This policy can be used if the customer is not ready to wait the time it takes for the product being made (Oscarsson et.al, 2006). When using this policy, forecasts of the expected demand have to be performed to approximately know how much to produce before an order has been confirmed (Oscarsson et al, 2006).

In each part in the logistics pipe, there is usually an inventory kept. The BMI is held to supply the production. The size of the BMI depends on the uncertainties of the deliveries and orders (Coyle et al, 2003). Higher uncertainty results in a larger BMI. The Base material is stored until needed in the production. Once the material is in the production, it is processed in a manufacturing process. If there is more than one process, it is sometimes necessary to have a buffer between the processes to maintain the production flow. The buffer is called WIP. The buffers will avoid shutdown of the entire production hence to breakdown of a single manufacturing process. The buffers will also balance the flow due to different process times (Stock and Lambert, 2001).

When the last manufacturing operation has been performed, the product is transported and stored in the FGI. The different parts of the logistics pipe can be seen in Figure 7.

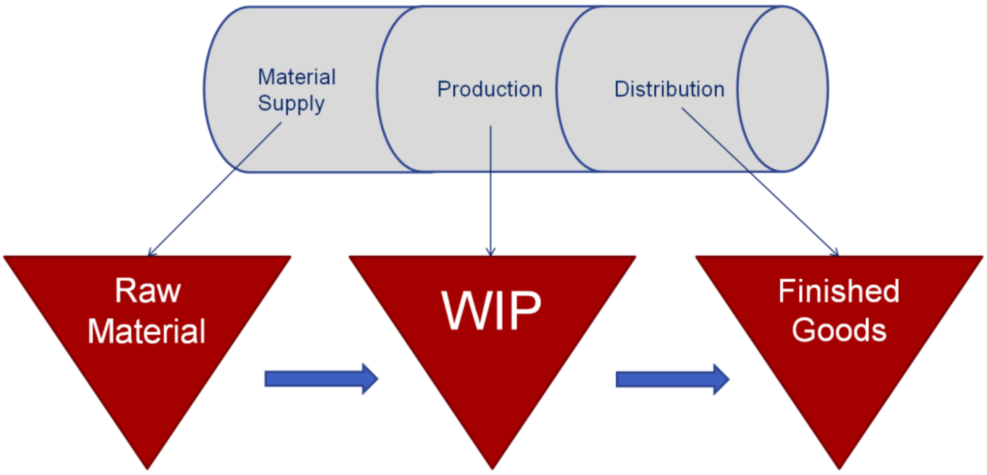

Figure 7: Inventory in a Producing Company

From the FGI, the product is ready to be delivered either directly to the customer or to a Distribution Centre (DC).

3.2 Warehousing and Storage Activities

The key activities in warehousing are Receiving, Put-away, Storage, Picking and finally Packing/Shipping (Frazelle, 2002). In addition, the storage policy and placing policy is of importance in the warehouse. The first activities when goods arrive are the receiving and put-away. Thereafter, the goods are stored until demanded (Coyle et al, 2003). According to Frazelle (2002), once there is a demand for a certain goods, there are three main departure activities. First the goods are picked according to the customers demand and thereafter, the goods will be packed and shipped. These activities are visualized in Figure 8.

Figure 8: Warehouse activities (Bartholdi and Hackman, 2011)

3.2.1 Receiving

Receiving is the phase where the goods are entering the warehouse. Almost immediately when a product is received, it is unloaded and prepared for put-away. A common way to register that a product has entered the warehouse is to scan the label so ownerships change and payments are sent. A very common way for a product to arrive in warehouse is on pallets (Bartholdi and Hackman, 2011). Pallets will simplify the handling of the product and will therefore reduce the workload. The receiving phase will charge the activity account for about 15% of the total activity done in a typical distribution centre (Frazelle, 2002).

3.2.2 Put-away

Put-away is the part where the product is transported from the receiving area and placed in storage. If the warehouse has a Warehouse Management System (WMS), the system will decide where the product will be stored. The locations of the storage may be very crucial in the long run regarding to the travelling distance for the forklifts, which off course can be associated with the economics for a warehouse. A good investment can be a WMS-system that optimizes the location for a product with respect to different parameters. When a product is put-away it is important to register the locations so efficient pick list can be created later. Put-away typically represent 20% of the total activity in a warehouse (Frazelle, 2002).

3.2.3 Storage

There are many different strategies regarding to how to place and store the goods in a warehouse. The cheapest and simplest way of storing goods on pallets are in so called *Ground Storage* (Hompel and Schmidt, 2007). The goods are placed directly on the floor and thereafter stacked on top of each other. If the goods are placed in large blocks, the space utilization is high due to the high density of the goods (Hompel and Schmidt, 2007). However, there is a low flexibility due to forced Last-In-First-Out strategy (LIFO); only goods from the first row can be picked. Typical ground block storage is illustrated in Figure 9.

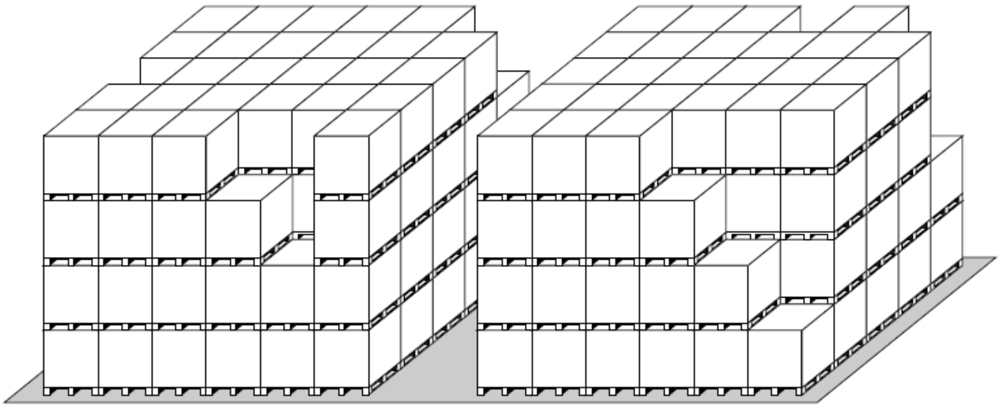

Figure 9: Ground Block Storage (Hompel and Schmidt, 2007)

If the ground storage consists of smaller blocks, or *lines,* the flexibility increases significantly; a forklift can enter the small aisles and pick any goods from the side. However, the space utilization decreases due to the increased amount of aisles. In Figure 10 is an illustration of typical ground line storage.

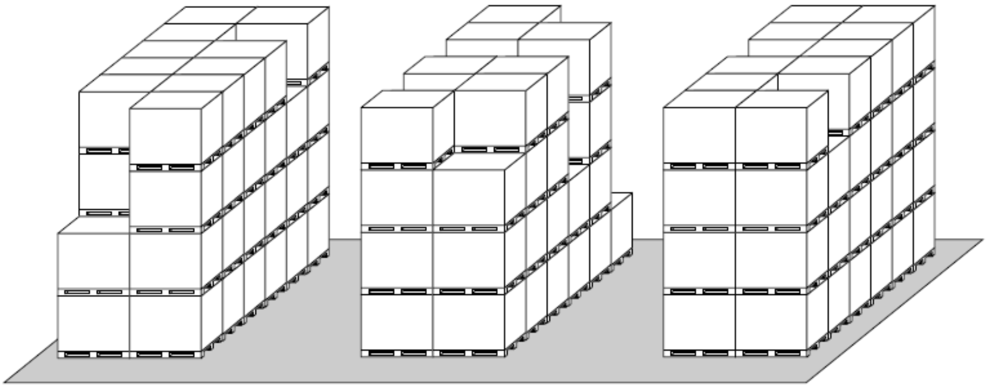

Figure 10: Ground line storage (Hompel and Schmidt, 2007)

The goods are placed in a lines, or *bins,* which is at least the width of a pallet wide. For example, a bin in Figure 11 is three pallets deep if picking occurs from the aisle in the figure. In general, deeper bin means higher space utilization. The depth of each bin is not easily decided. It depends on how accessible each goods needs to be. If shared storage is used, there will always be double handling of goods if the bin depth is more than one pallet. This means that if there is a deep bin and the first pallet that was place in the bin is ordered, all other pallets must be moved. This is a very time consuming activity and adds no value (Bartholdi and Hackman, 2011).

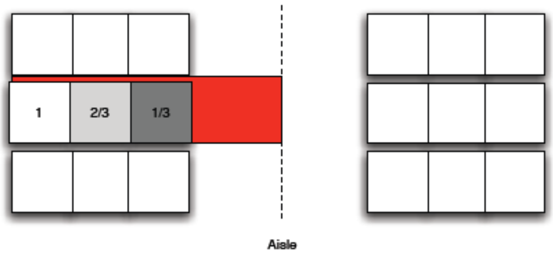

Figure 11: Bin depth (Bartholdi and Hackman, 2011)

Dedicated and Shared storage: Each location for a pallet in a warehouse has its own unique address (Bartholdi and Hackman, 2011). This concern both shared and dedicated storage. Storage in a warehouse will have a substantial cost, because storage will occupy space within the warehouse and associated with rent, security, staff etc. Storage in general will include special handling equipment in form of shelves, rack, which is a cost for the company. The two main strategies within storage is *shared* and *dedicated* storage (Bartholdi and Hackman, 2011). The dedicated one is less complex than the shared one (Bartholdi and Hackman, 2011). Dedicated storage is when each SKU has its own location in the warehouse and no other SKU will or can be placed in this reserved bin. Even if it is a better location temporarily for another SKU, it has to be placed somewhere else. Because of the location of the SKUs does not change, it will be easy to plan so the most frequent SKUs will get the best places in the warehouse and will make the order-picking much more efficient. The disadvantage of the dedicated storage is that it does not utilize the space as much as the shared storage in the warehouse. In large warehouses with many thousands of SKUs, there will be approximately an average of 50% in space utilization (Bartholdi and Hackman, 2011).

If the warehouse is in need of improving the space utilization, they could try to change the way of storing SKUs and implement the shared storage strategy. This storage strategy will try to assign the SKU to more than one place. Shared storage is based on when any pallet position becomes empty and available, any another SKU can be placed in this bin. This is more efficient than waiting until a certain SKU comes and claims its unique place in the warehouse. This strategy is of course more complex and has its own disadvantages. The employees cannot learn the location of the SKUs and have to have a WMS to help them finding and keep track of everything. The WMS will help the employees and direct them to the right storage location. One disadvantage is that it is more time-consuming to put-away recently received SKUs. The SKUs might be taken to different places in the warehouse for storing (Bartholdi and Hackman, 2011).

3.2.4 Picking

A pick is when an order is removed from its storage and transported to the area where it will be prepared for shipping. Once an order is received, it is time to create a pick list. Before the pick list can be designed, the product must be checked if it is ready for shipping. Picking represents 50% of the activity of a typical warehouse. (Frazelle, 2002). Picking activities are listed in Table 2.

Activity	% Order-picking time
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

Table 2: Picking activity (Frazelle, 2002)

3.2.5 Shipping

In general, shipping handles larger units than picking unless a unit-load warehouse (Bartholdi and Hackman, 2011). Products are most likely to be arranged due to its transportation. If there are different orders in the same truck, the orders that will be delivered last will be loaded first (LIFO). A scanning sequence of the product is most likely to occur, so the warehouse can keep track of what that has been shipped. The shipping regulations vary from each warehouse depending of in which country the warehouse is located, due to national laws and conditions.

3.2.6 Bin size

There are many ways to set sizes for different objects in a warehouse. The bin size in a warehouse can be described as how many SKUs that can be stored at each level. To minimize the total average floor space consumed by a pallet, the bin size can be calculated approximately according to Equation 1 (Bartholdi and Hackman ,2011).

$$\text{k}=\sqrt{\frac{a*1*\sum_{i=1}^{n}\frac{q_i}{z_i}}{2*n}}$$

Equation 1

Equation parameters are shown in Table 3: Equation Parameters.

K= the depth of the bins

q_i=order quantity

z_i= stack height in number of SKUs

n= number SKU´s

a= aisle width

Table 3: Equation Parameters

3.2.7 Warehouse Management System

Some warehouses of today are very large and complex. A warehouse could contain thousands of SKUs and could have many employees. WMS is a complex software. It keeps track of all the storage locations and helps managing the inventory. The WMS will make sure that everything is handled and picked correctly and as fast and efficient as possible (Bartholdi and Hackman, 2011). The WMS knows about every product which is stored in the warehouse. It knows the dimension, the quantity and all other important information regarding the product. With this information, it is possible to coordinate the warehouse operations in a very efficient way. The WMS will prepare a picking list for the pickers to decrease the picking time as much as possible. The WMS can also consolidate different orders with each other to create savings. Due to the WMS, the pace in the supply chain has increased greatly in the last 20 years (Bartholdi and Hackman, 2011). Accurate, controlled product will move faster in the supply chain and give better service to the customer. It will also decrease the lead-time for inventories in the system.

Basic features of most WMS's include tools to support (Bartholdi and Hackman, 2011):

- Appointment scheduling
- Receiving
- Quality assurance
- Put-away
- Location tracking
- Work-order management
- Picking
- Packing and consolidation
- Shipping

3.3 Warehousing Costs

All activities in a producing company create a cost. Two main cost groups are taken into account; the Life Cycle-Cost and The Warehousing Cost. The general definitions are first presented. Thereafter, the cost definitions for the Arganda factory are presented which will be used when comparing the different scenarios.

3.3.1 Holding Costs

By keeping a stock, capital is tied up which could have been invested or kept in the bank with a return of interest (Axsäter, 2006). Therefore, the keeping of stock will contribute to a potential loss of revenue (Oscarsson et al, 2006). This capital cost is often the major part of the total holding cost. Other costs could be obsolescence, insurance, waste and damages (Oscarsson et al, 2006). The holding cost is usually presented as a cost per unit and time.

3.3.2 Handling Costs

The Warehousing and Handling cost are all the costs related to operate a warehouse. All costs for personnel and transport within the facility are included in the warehousing cost (Oscarsson et al, 2006). In addition, the building itself creates costs such as heating, maintenance etc. There are costs related to the handling of the arriving goods as well as the departing goods. Receiving, putaway, picking and shipping are examples of activities creating a handling cost.

3.3.3 Life-Cycle Cost

Throughout the life time of a product, there will be a number of costs which the product is accounted for. First of all, there are costs involved when it comes to the development and research of a new and/or existing product. Once developed, it will take the next step in the life cycle; the production. It starts with base material and or semi produced components which have to be ordered. Thereafter, the base material will be transported to the production site, where it will be refined in a number of different activities. If the manufacturing of the product requires many activities, sometimes buffers or WIP-stock must be held. The manufacturing will finally be finished and the product will be transported. It can be transported directly to the customer or to a DC where it will be stored and later on distributed. Finally, the end-consumer will purchase, use and dispose or recycle the product. The general life-cycle of a product can be seen in Figure 12.

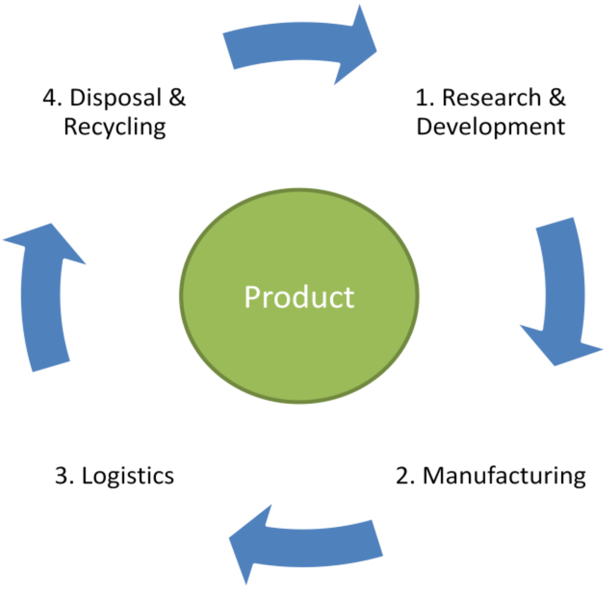

Figure 12: Life-Cycle Cost

Each activity in a factory chain is related to a cost. By decreasing a cost of an activity without considering the effect on the other activities in the factory chain, the result may be a sub-optimization with an increased total cost (Stock and Lambert, 2001)[2]. The total cost can only be reduced by using the systems approach, which is a more holistic approach to the entire system where sub-optimization is not performed (Stock and Lambert, 2001).

3.3.4 Cost Definitions Arganda factory

The total holding cost in Arganda: can be calculated by taking the average inventory level in the model multiplied by the average stay time in racks for the warehouse.

The handling cost: will be calculated and compared. Relocation is when a SKU is moved if blocking an ordered SKU. By multiplying the handling cost with the relocation factor, the cost for unnecessary movement will be revealed. The handling cost is distributed between the material handling activities; receiving, put-away, picking and shipping. 50 % of the total handling cost can be associated with the picking activity. Relocation only occurs in the picking activity. As seen in Table 2, the picking activity is divided into different sub-activities. Therefore, it is assumed that the *Relocation Cost is* 50 % of the picking cost or 25 % of the Handling cost.

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[2] Referring to Joseph Cavinato: “a total cost/value model for supply chain competiveness” Journal of Business Logistics 12no. 2 1992 pp 285-301

The travelling cost for the forklifts is 55 % of the picking activity. Assuming that the cost is evenly distributed over the different sub-activities, the travelling cost is set to 55% of the picking cost. This assumption results in that the travelling cost is 27.5 % of the Handling Cost.

The cost equations can be seen in Table 4: Cost Equations.

Relocation cost (RC)	= 25% of handling cost = 15.7/4 = **3.93€**
Total RC per day	= RC per SKU * Average amount of Relocations per day
Annual RC	= 50 weeks*5 days*Total RC per day
Total Holding Cost (HC) per day	= Average Inventory level* stay time(days) per SKU * HC
Annual HC	= 50 weeks*5 days*Total HC per day
Annual measured Cost	= Annual HC + Annual RC
Travel Cost per meter	$= \frac{\text{Avg.Travel distance per SKU}}{\text{Total throughput} * \text{Travelling Cost}}$
Average Travel distance per SKU	$= \frac{Total\ travel\ distance}{Total\ throughput + Number\ of\ relocations}$
Total Travel Cost per day	= Travel Cost per meter*Total Travel Distance/7
Annual Travelling Cost	= 50weeks*5days a week* Average traveling cost per day

Table 4: Cost Equations

4. Finished Goods Inventory Description

This chapter will include a system description of the FGI in Arganda. The layout will be described as well as the SKU flow process. The stakeholders will be presented and the key stakeholders more thoroughly described.

4.1 Layout

The warehouse in Arganda divided into three main areas; FGI, WIP and Additional Material. Each area is accessible through gates where the forklifts can drive and the pedestrians can walk. In Figure 13, the three main areas are visualized.

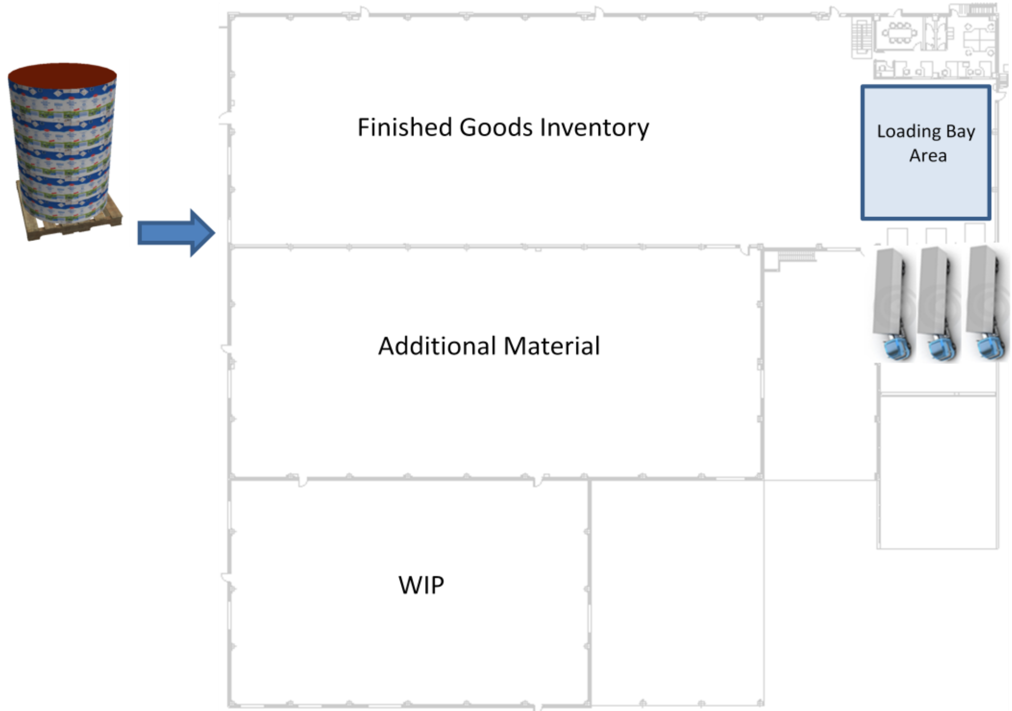


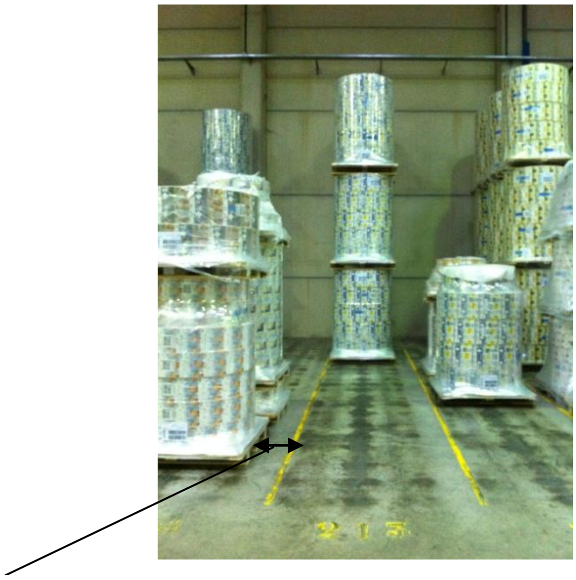
Figure 13: Layout Warehouse Arganda

4.1.1 Finished Goods Inventory

The Finished Goods Inventory has different capacity in the bins. A pallet position represents the floor space occupied by a SKU. The bins have capacity from 6-30 numbers of SKUs. There is also a Vendor Managed Inventory (VMI) section in closest region to the loading bay area which is used from time to time. Figure 14 shows the bin layout of the FGI.

Figure 14: Bin Distribution Arganda

The bins have a width of 1500mm. This means that there is additional space in each bin when a SKU is stored there hence to the width of a SKU which is 1150mm. The additional space enables a person to walk between the bins to look when a certain SKU has to be located. The forklift drivers are instructed to place all SKUs to the left in each bin to create the additional space. This can be seen in Figure 15.



Additional space

Figure 15: Bin width

The most common size of a bin is three pallet positions and the least common size is ten pallet positions. The total FGI capacity is summarized in Table 5.

Bins		
SKU Capacity / Bin	**Number of Bins**	**Total SKU Capacity**
30	3	90
27	6	162
24	8	192
21	6	126
18	16	288
15	12	180
12	4	48
9	38	342
6	21	126
	114	**1554***

Table 5: Bins FGI

*When each pallet position stores three SKUs

There is no dedicated pre-staging area in the FGI in Arganda. The loading bay area is only used during the night as a pre-staging area, for the morning shipments to the external warehouse. The forklift driver get a picking list from the administration department and are supposed to pick the order and deliver it directly to the truck driver, which will load it on the truck himself. Table 6 shows the specification of the FGI:

FGI Arganda	
Maximum capacity	1554 SKUs
Average in stock	1200 SKUs
Weekly turnover	3000 SKUs
Daily throughput	600 SKUs
Throughput time	2 days

Table 6: Material Flow Arganda (José Maria Escrich 2012)

Main Aisle: There is a main aisle, see Figure 16, in the middle of the FGI which is heavily trafficked and 5 smaller crossroads where additional bins can be reached.

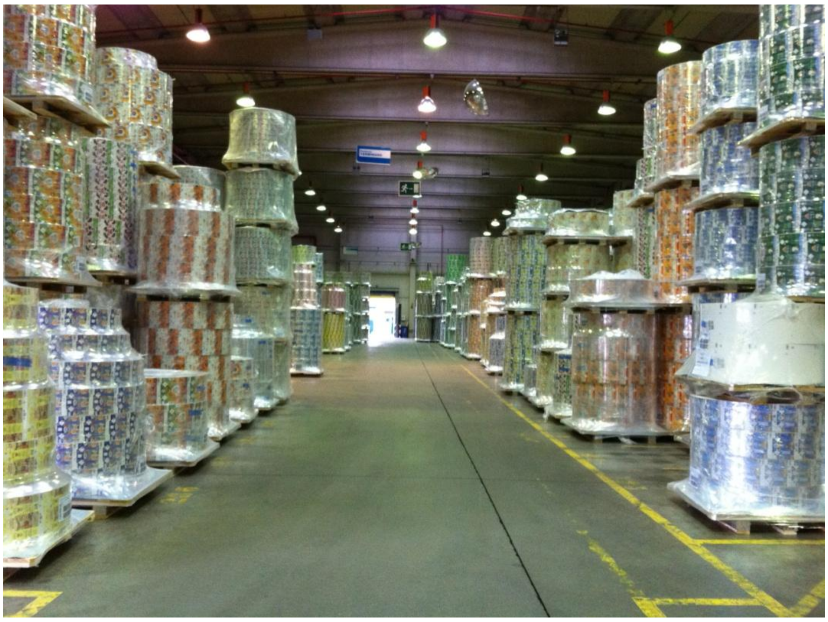


Figure 16: Main Aisle seen from Loading Bay Area

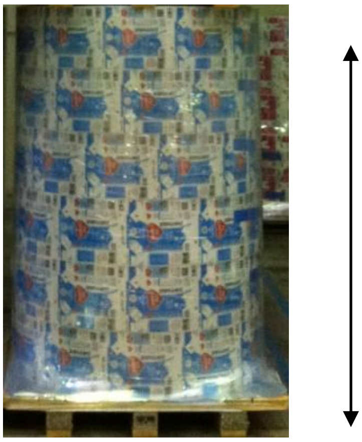
The main aisle has two-way traffic and forklifts can meet without yielding. If a SKU is picked from a bin with entrance from the main aisle, other forklift drivers give way for the picking forklift. Pedestrians can walk within the restricting lines in the main aisle.

4.2 Storage Keeping Unit

The SKU consists of a wooden pallet, with different amount of reels of packaging material on it, see Figure 17. The SKU is wrapped in plastic to prevent any damage during transport or storage. The SKU has a label with all the necessary information. The dimensions of the pallet are not the traditional Euro pallet dimensions. There are seven different types of reels that could be stacked on a SKU. These different types are related to the size of the carton package which will affect the width of the reel. The standard sized SKU has five reels and weighs approximately 1100 kg.

Dimensions:

- Pallet dimensions: 1150x1150x140 mm
- The maximum allowed height of a SKU is 1755mm (including the pallet)
- The minimum height of a SKU is 320mm (including the pallet)
- The average dimension of a SKU is 1670mm
- Average number of reels on a pallet is 5.



6 reels on a pallet

Figure 17: SKU

4.3 SKU Flow Process

The FGI in Arganda operates 24 hours a day, 5 days a week since there are only arriving SKUs from Monday morning to Saturday morning. The picking process is only operating 12 hours per day 08.00-20.00, 5 days per week.

Finishing Area

The Finishing Area is the last step in the production process. The mother rolls arrive there after being printed and laminated. At the Finishing Area, the mother rolls will be mounted in a slitting machine and divided into reels containing a single row of packages, see Figure 18. The reels are thereafter stacked on a pallet and transported to a plastic wrapper. Today, there is a major project which involves the rebuilding of the Finishing Area in Arganda. This has had some impact on the FGI; The Automated Guided Vehicles (AGVs) have a significantly shorter distance to travel to unload in the FGI compared to before the rebuilding. One of the results is that there are less AGVs able to queue up for unloading in the FGI than before. Another result is that sometimes the AGV fail to pick the SKU from the plastic wrapper due to errors in the new programming. The outcome is that the forklift drivers have to manually pick the SKU instead of the AGV from the plastic wrapper. The Finishing Area operates Monday to Friday, 24 hours a day. The last shift ends on Saturday morning at 6 am.

Figure 18: Slitting Process

Transport to Finished Goods Inventory

Each time a SKU leaves the Finishing Area, it will be logged in the factory master computer. The data consists of all relevant data for each SKU such as number of reels, height of a reel, reel diameter etc. See Appendix III for detailed data. Each production order has a unique number which represents the quality and type of packaging material the specific customer has ordered.

Once the SKU is wrapped in plastic and labeled in the Finishing Area, it is picked up and transported to the FGI by an AGV, see Figure 18:1. When the AGV arrives to the FGI, it places the SKU on a conveyor belt with a total capacity of five SKUs, see Figure 19:3. If the maximum capacity is reached, the AGVs will queue up outside the FGI. The AGVs are always prioritized regarding the traffic occurring between the Finishing Area and the FGI. This means that pedestrians and forklifts will wait until the AGVs have passed. The number of AGVs is 20 in Arganda, but not all the AGVs transport SKUs to the FGI. The AGVs has different task along the whole production. However, the transport to the FGI is a prioritized task for the AGVs. In general, there are 5-10 AGVs transporting SKUs to the FGI.

Figure 19: Transport to FGI

Receiving

Once the SKU has arrived to the FGI, it will be placed on a 6m long conveyor belt which has a speed of approximately 0.2 m/s. There is a delay time between that the AGV has placed the SKU on the conveyor belt and when the conveyor belt will actually start transporting the SKU. This safety delay will guarantee that the AGV has exited the receiving zone. Once the SKU has reached the endpoint of the conveyor belt it is received by a forklift, see Figure 20. The forklift driver picks the SKU and scans the barcode of the label. The data received provides relevant data regarding the SKU; order, batch, what type of text is printed and so on. The data is loaded into a WMS system called Witron. For the first SKU in an order, it automatically suggests an available bin in the FGI. The forklift driver has to decide if the suggested bin is appropriate for the current order size or not. For example, if the suggested bin is too small for the order, a larger available bin is chosen. The forklift driver manually changes the bin in the WMS- system. The WMS-system will then suggest the manually chosen bin for the following SKUs in the same order.

Figure 20: Conveyor Belt

Put-away

The SKU is placed in the chosen bin once it has been received and scanned, see Figure 21. The maximum height of the stacked SKUs in the warehouse is not allowed to be higher than 5300 mm due to insurance policies. The standard SKU size is 1670 mm which allows a stacking number of three. If the SKUs are to be transported in a container, the SKUs have a lower height, approximately 1060 mm. This allows the SKUs to have a stacking number of five in the warehouse. The reason for the lower height is that in a standard container with a height of 2400mm, the stacking number is two.

Figure 21: Put-Away of received SKU

There is another constraint regarding the stacking. All SKUs are not allowed to be stacked on each other. The bottom deck board must be able to distribute the weight of the pallet, see Figure 22. To guarantee a safe working environment, a study has been made in this field (Escrich, 2012). The study showed that the top reel diameter cannot be smaller than 975 mm.

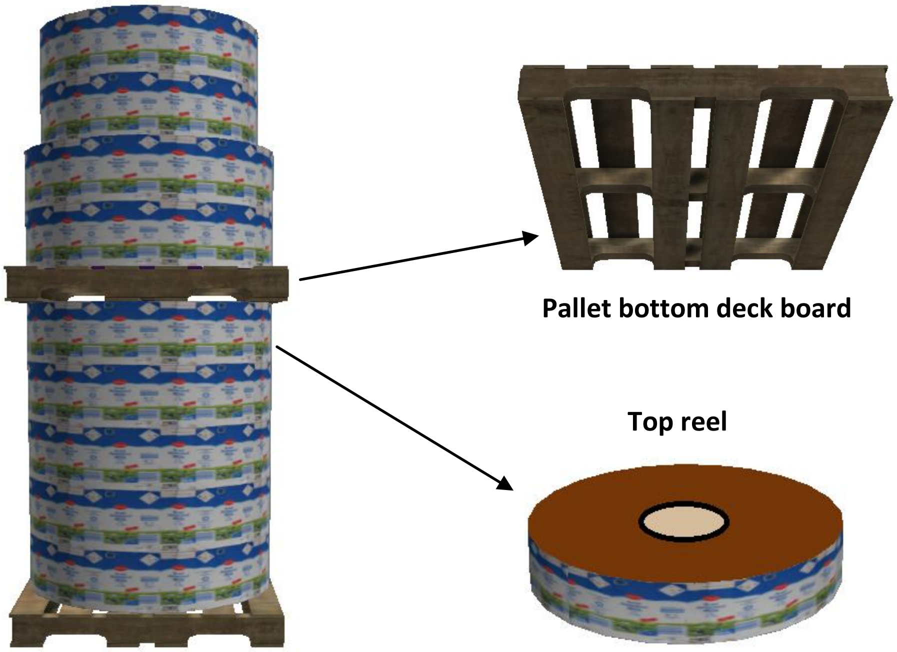


Figure 22: SKU stacking

Picking

The forklift driver receives a picking list from the shipping office with which order and the amount of SKUs that are to be loaded on the awaiting trucks or containers. The forklift driver picks the SKU and immediately scans it as “picked”. This will inform the WMS-system that the SKU is no longer in stock. Since the FGI has lanes with mixed orders due to lack of space, there is a chance that the SKU that will be picked is blocked by other SKUs. If that happens, the forklift driver has to find another available bin to place the blocking SKUs in. Each SKU that is moved will be scanned and the new bin location is updated in the WMS-system. Once the SKU is picked according to the picking list, it is transported to the loading bay area.

Loading

When the SKU is picked and transported from the bin, it will be unloaded in the loading bay area, see Figure 24. Thereafter, it is picked up by a pallet truck (Figure 25) and placed inside the truck or container. Some deliveries also require additional material such as plastic polymers which are used in the ejection molding of the caps. The additional material will then be shipped together with the packaging material. There are three loading docks which can be used simultaneously, see Figure 23. One of the docks can be used for both containers and trucks while the other two docks are only used for trucks. The trucks and containers are docked at a *first-come-first-served* basis unless it is a rush order. The trucks to customers are only loaded 08.00-20.00. This gives the evening shift time to pre-stage two truckloads in the loading bay area for the following morning. These trucks will arrive at 06.00 in the morning and will depart for the external warehouse in Azuqueca de Henares. Consolidation of different customer orders in the same truck or container is not applied when transporting to the customer. It is only applied when transporting to the external warehouse to have as many full truckloads as possible. It takes approximately 10 minutes between the undocking of the first truck until the start of loading the following truck. During this time, the first truck will exit the docking area and a waiting truck will enter the loading area to dock. Once the truck has been docked, the truck driver will hand over the shipping documents. Thereafter, the loading of the truck can begin.

Figure 24: Loading Bay Area

Figure 23: Loading Docks

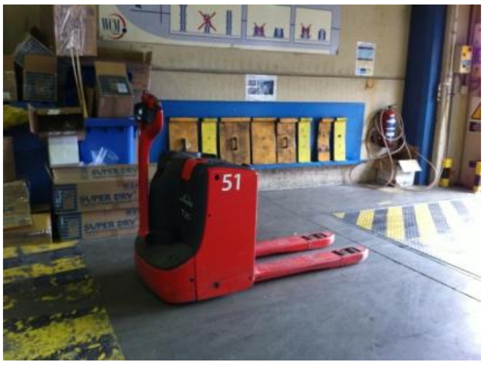


Figure 25: Pallet Truck

4.3.1 SKU Flow Chart Finished Goods Inventory

Figure 26 presents each step in the SKU process and all the concerned activities. The flow chart is presented on the next page. The following steps and decisions have been identified:

1. SKU arrives to the FGI and placed on a conveyor belt
2. The SKU is transported by the conveyor belt to the receiving location.
3. Is it a rush order?
    - 3a. YES.

      The SKU is not scanned and are transported directly to the loading bay area.
    - 3b. NO.

      The SKU is picked up and scanned.
4. The WMS-system suggests a random place in the warehouse.
5. The receiving forklift lift driver decides if the SKU should be placed in the recommended bin or to choose another bin.
6. The SKU is placed in the chosen bin.
7. The receiving forklift driver updates the WMS -system where the SKU has been placed
8. A picking list is delivered to the picking forklift driver by the shipping office.
9. The picking forklift driver arrives to the given bin to pick up the SKU.
10. Is there other pallets blocking the picking for the SKU?
    - 10a. YES.

      He picks up the other SKUs and places them in another bin and updates the WMS - system where the SKUs have been replaced.
    - 10b. NO.

      He picks up the SKU and scans it.
11. SKU is transported to loading area
12. SKU is placed in the loading area
13. Is the shipping associated with a container?
    - a. YES

      One of the picking forklift drivers will do the loading of the container.
14. Pallet is picked by truck driver

END: Pallet is placed in the truck or container.

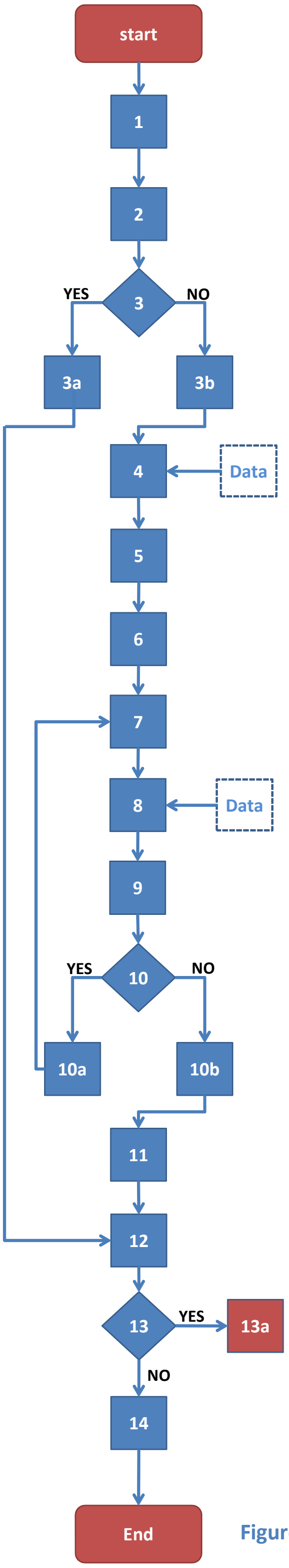


Figure 26: SKU Flow Chart Arganda

4.4 Stakeholders

Each stakeholder influencing the system must be identified as well as which level of involvement they have. By discussing with personnel working in the FGI and the responsible managers, all relevant stakeholders have been identified. Figure 27 is visualizing the level of influence the stakeholders have on the FGI.

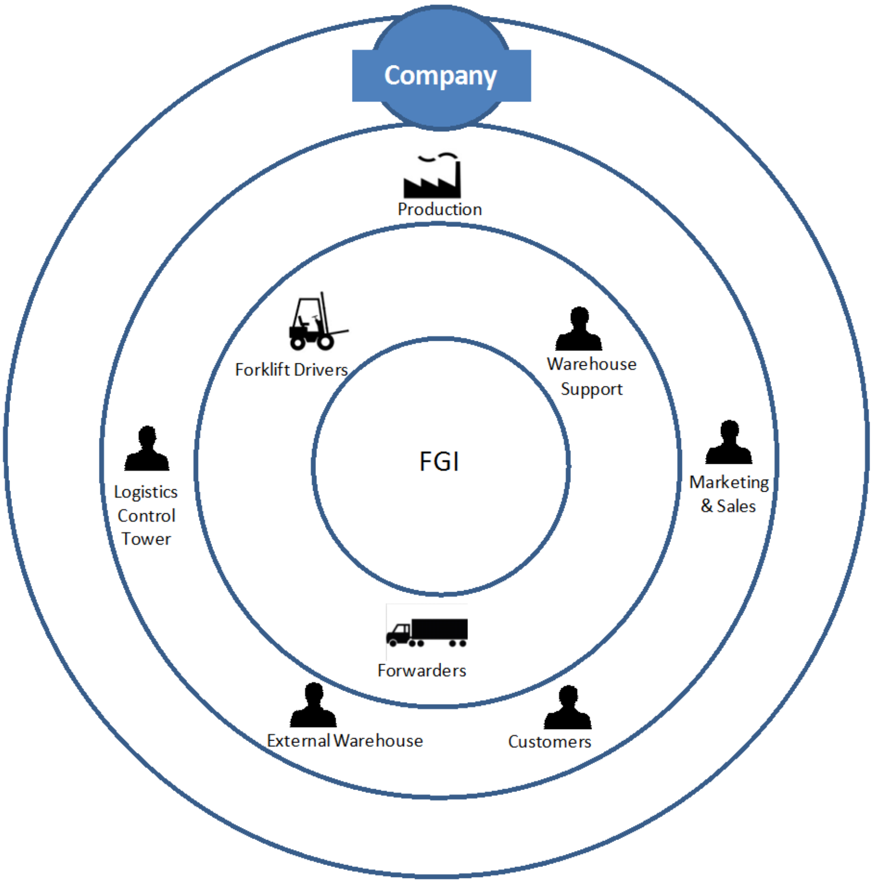


Figure 27: Stakeholders

The inner circle is representing the system. Forklift drivers, Warehouse Support and Forwarders are all involved in the activities that are directly related to the improvements that will be analyzed in the simulation of the FGI. The middle circle contains the Customers, Logistics Control Tower and Market & Sales which all have an indirect influence on the FGI due to order and shipping size. The outer circle represents the Company as a global company which will benefit by having lower costs and an additional part in their simulation model library. Forklift Drivers, Forwarders, Customers and External Warehouse will be more thoroughly described.

4.4.1 Forklift Drivers

The forklift drivers are the vast majority of the personnel working in the FGI. They have been separated into two teams; *Picking* and *Receiving*. The average salary for a forklift driver is 36 400€ per year (Escrich 2012).

The Receiving team of two forklift drivers is handling the receiving and put-away of the SKUs. In addition, they also supply the Production with aluminum foil and supply the Finishing Area with empty pallets. A light will be turned on in the FGI receiving area when pallets or aluminum is needed. It takes about 5-10 minutes to supply the Finishing Area and it has to be done approximately 15 times per shift. The supplying of aluminum foil takes about 15 minutes and has to be done four times per shift. However, the production does not always use aluminum in the production (Garcia, 2012). The receiving team working hours can be seen in Table 7.

Working hours Receiving team	Monday - Sunday
Shift 1	07.50 – 15.50
Shift 2	15.50 – 23.50
Shift 3	23.50 – 07.50

Table 7: Working hours receiving team

The shifts are overlapping each other with 10 minutes so usually the forklift drivers arrive to the FGI 10 minutes before the shift starts. Each forklift driver is entitled to one hour break per shift. It is usually divided into a larger break, 30-40 min, followed by smaller 10 minute breaks. At night, the receiving shift is losing one man-hour due to covering for other forklift drivers working in the WIP inventory or BMI when they have breaks (Garcia 2012).

The Picking team is assigned to pick and transport the SKUs according to the picking list. In addition, the team is also loading containers. One of the forklift drivers is always assigned to unload trucks with empty pallets and cores[3], put-away the empty pallets and cores and finally supply the production with empty cores. The Picking team has an overlapping shift with one additional forklift driver during the peak hours of truck arrivals. Each forklift driver is entitled to one hour break per shift. It is usually divided into a larger break, 30-40 min, followed by smaller 10 min breaks. The picking team working hours can be seen in Table 8.

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[3] A core is a tube of corrugated cardboard where the packaging material is rolled up on.

Working hours Picking team	Monday – Friday
Shift 1: 3 forklift drivers	07.50 – 15.50
Shift 2: 1 forklift driver	11.00 – 19.00
Shift 3: 2 forklift drivers	15.50 – 23.50

Table 8: Working hours Picking team

4.4.2 Forwarders

All shipments from the FGI are made by road. The load carrier is either a truck with a trailer or a truck carrying a container. The container can be transported to a harbor for further transportation by sea. The trailer is usually delivered directly to the customer.

Containers: All containers are loaded by the Company FGI personnel. When the standard container-SKU is loaded in the container, the stacking number is two except for Japan, where the stacking number is one. Since the shipment will go by sea, there are number of safety measures to apply. To avoid moist and mold in the pallets, moisture absorbing bags are placed underneath the pallet. To avoid the stacked SKUs to tip over or be knocked in to the container wall, large air bags are placed to protect the SKUs. In addition, all SKUs are strapped tightly and secured. These additional measures contribute to a longer loading time and increased workload for the fork lift drivers. A container takes approximately 1-2 hours to load depending on the amount of SKUs loaded. A container must be loaded within three hours from the agreed shipping time. Otherwise, Company will have to pay a fee of 45 euro/hour. SKUs are loaded in both 20 ft (Figure 28) and 40 ft containers, but the 40 ft container is more common.

Figure 28: 20ft container

The container dimensions can be found in Table 9 (Ocean Container dimensions, 2012).

Container	20 feet	40 feet
Inside Height	2.38m	2.38m
Inside Width	2.33m	2.33m
Inside Length	5.89m	12.01m

Table 9 Container dimensions

These dimensions and with the stackability of 2 will lead to 20 SKUs in a 20 ft container. The 40 ft container has a max capacity of 40 container-sized SKUs, but due to weight constraints, it will only be loaded with approximately 36 SKUs.

Trailers: All trailers are loaded by the truck drivers. The domestic customers have their own trucks. The international transports are ordered through the Logistics Control Tower who orders the trucks from different forwarders. A trailer can load 22 standard SKUs which will not be stacked. When loaded with 22 SKUs, the truckload is close to the maximum weight allowed which is 24 tons. It takes approximately 30 minutes to load a trailer. If it is an international shipment, the SKUs have to be secured with protective material to avoid transportation damages. Once the trailer has been docked to the loading bay area, it must be loaded within 2 hours or a fee of 35€ per hour is debited (Escrich, 2012).

The dimensions of a trailer can vary, but the most common is the one presented in Figure 29.

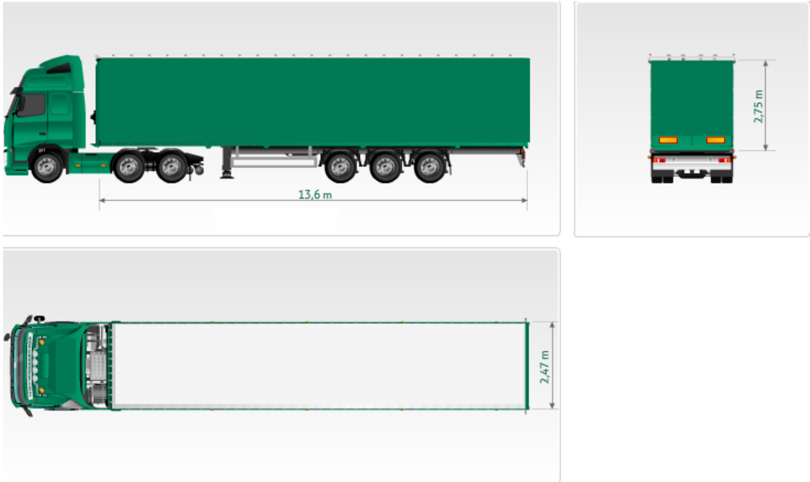

Figure 29: Standard Euroliner Truck (Standard Lastbilsflotta, 2012)

4.4.3 Domestic Customers

The domestic customers are applying VMI – system. This means that the customers are updated regarding their orders as soon as they have been produced. The information sent is how much of their orders that are placed in the FGI and how much of those are placed in the external warehouse. Since the domestic customers are 65% of the total shipments, they have a large influence (Escrich 2012). No delivery order has to be placed by the domestic customers and since the VMI is used, the customer trucks arrive whenever there is a need for packaging material. This situation makes it difficult for the shipping office to plan the loading in advance. The lead time, which is the time from an order is placed to Estimated Time of Dispatch (ETD), is 14 days and the invoice is sent as soon as the order has been produced. The domestic customers places larger orders compared to the international customers and the orders are stored significantly longer in the FGI. This is a result of the use of the VMI-system in a combination with that the invoice is sent directly when the order is produced. The customer can therefore use the FGI to store their own goods as long as possible.

4.4.4 International Customers

The international customers are approximately 35 % of the total shipments, where 25 % are delivered to Portugal and the remaining 10 % to the rest of the world (Escrich, 2012). Each customer places a delivery order when the production order is placed. This will make it possible for the shipping office to order trucks from the Logistics Control Tower. The lead time, *order – ETD,* is 14 days and the invoice is sent when the truck has been loaded and dispatched. A security guard ensures that all documents are in order and that nothing else is loaded on the truck except what is on the shipping list.

4.4.5 External Warehouse

About 200 SKUs of the total daily shipments goes to an external warehouse in Azuqueca de Henares which is located 46 km from Arganda. This warehouse has an additional capacity of 4800 SKUs. This warehouse also supplies the factory in Arganda with raw material goods multiple times a day by truck loads. Approximately 50 % of these trucks return to the external warehouse with finished goods in order to save transportation costs (Escrich, 2012).

4.5 Key Performance Indicators

The FGI in Arganda is evaluated with the following KPIs:

- Perfect Delivery
    - Order delivered on time
    - Order delivered in full
- Inventory Level

The Perfect Delivery contains both order delivered on time and order delivered in full. Order delivered on time was until recently measured at the ETD. Order delivered in full has a ±5 % deviation from the actual order size to be considered full.

5. Simulation Model

This chapter contains a detailed description of how the simulation model has been constructed with all the different processes. The result from the validation of the model will be presented as well as improvement scenarios which will be part of the experiments.

5.1 Model Description

The model represents a non-terminating system, which means that there is no specific stop when the simulation is over. Since there are no incoming SKUs during the weekend and no departing SKUs either, the weekend will not be part of the simulation. Figure 30 shows an overview of the complete model of the FGI and the AGV path from the Finishing Area.

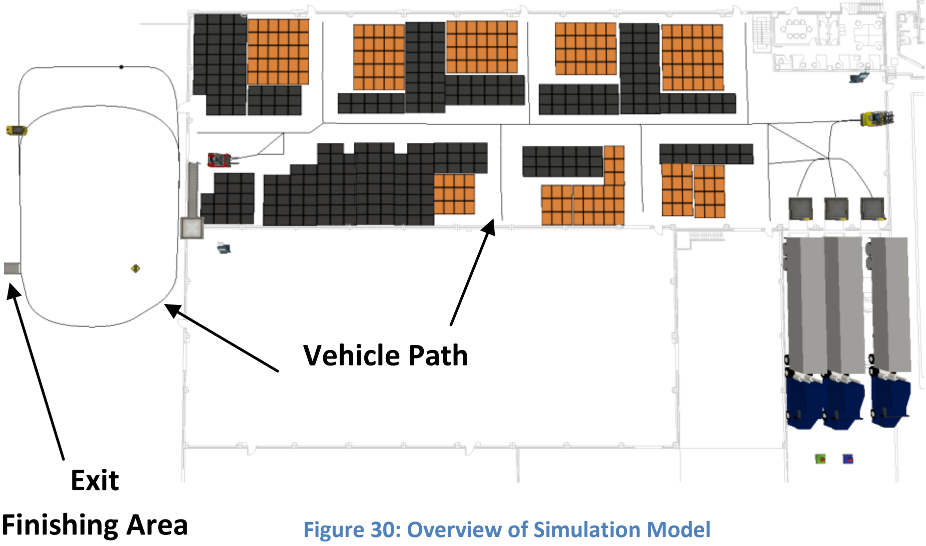

Figure 30: Overview of Simulation Model

5.1.1 Layout Finished Goods Inventory

A digital blueprint of the FGI is used for the model to obtain the correct measurements. The current layout of the FGI is used in the model. In the model, the FGI will be structured by 27 different floor storage zones which represent the different areas of bins. The bins are divided into pallet positions, which are the squares in the floor storage zones seen in Figure 31. The pallet position that the SKU is placed in has the dimensions of 1150*1500 mm and the stacking number depends totally on the height and diameter of the SKUs.The high amount of floor storage zones will increase the accuracy when a SKU will be relocated due to blocking SKUs. SKUs can therefore more easily be sent between the different objects based on the need of relocating SKUs. The light coloured floor storage zones are entered from the side aisles and the dark coloured floor storage zones are entered from the main aisle.

Figure 31: Layout FGI

5.1.2 Storage Keeping Unit

The completion of the SKUs is performed at the exit of the Finishing Area. Reel by reel will be stacked on a pallet. The data for the generated reels consist of all relevant information regarding how many reels should be stacked on each pallet as well as the height of each reel etc. For a complete view of input data, see Appendix III. The SKUs consisting of wooden pallets with reels of packaging material will be the flow item in the simulation model. One production order can contain variety of SKUs. The SKU is always accessible for the forklift. The maximum diameter is set for the reason to make sure that the reels on the pallet do not reach outside the frame of the pallet. The SKUs that belongs to the same production order will get a specific colour. The colour simplifies the identification when the animation is watched and the stacking is controlled, the SKUs with the same colour should be stacked together. A virtual SKU is visualized in Figure 32.

Figure 32: SKU

When stacking, the minimum diameter allowed for the top reel of the SKU is 975 mm hence to the dimensions of the bottom structure of the wooden pallets. If the top reel diameter is any smaller than 975 mm, the stacked SKU will not be considered stable and has an increased risk of tipping over. The SKU dimensions can be seen in Table 10Table 10: SKU dimension.

SKU	
Max height	1755mm
Min height	320mm
Max diameter	1150mm
Pallet size	1150*1150mm

Table 10: SKU dimensions

5.2 SKU Flow Process

Transport to Finished Goods Inventory: The SKU is collected at the exit of the Finishing Area. Thereafter, it is transported to the entry of the FGI. All other vehicles and pedestrians give way for the AGVs when they are transporting from the Finishing Area to the FGI. The AGVs will follow a path with a single capacity; the vehicles cannot pass each other. The path, pickup point at the Finishing Area and the exit at the FGI are seen in Figure 33.

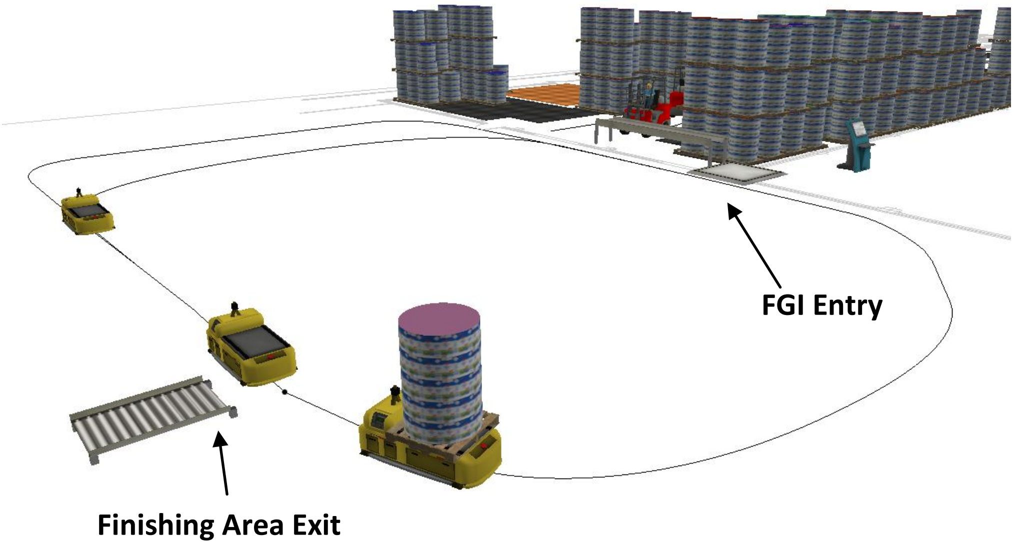

Figure 33: Transport to FGI

Receiving: In the receiving area there are two forklifts working during each shift. The SKU is placed on the receiving conveyor belt. The conveyor belt has a safety delay time of approximately 30 seconds that starts directly when the SKU is put-down on the conveyor belt. However, in the model there will be a longer unloading time for the AGV instead of a safety delay time. The virtual receiving activity is visualized in Figure 34.

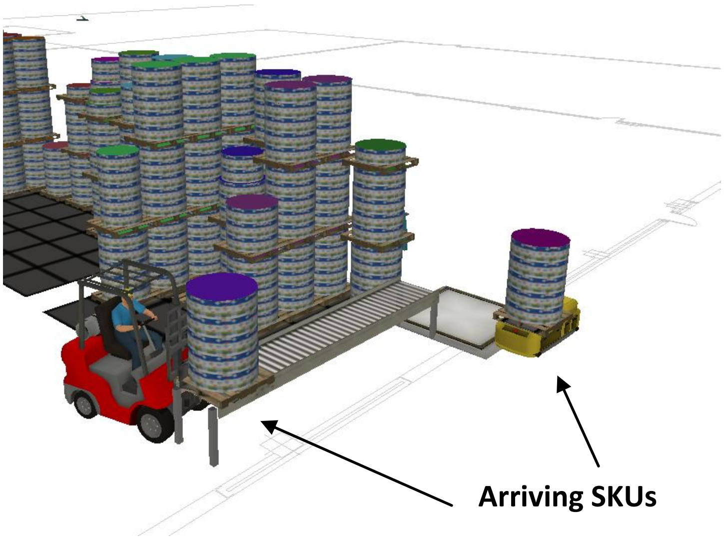

Figure 34: Receiving of an SKU in the FGI

The conveyor belt has a length of 6 meters and a speed of 0.2 m/s. The conveyor belt will have no breakdowns in the simulation model. After transportation on the conveyor belt, the SKU is ready to be picked by a forklift. The forklift picks the SKU from the conveyor belt. Each pick from the conveyor belt including the scanning of the SKU, is simulated with a triangular distribution of [11, 24, 16][4] seconds.

Put-away: The logic code will trigger when the SKU is on the conveyor belt and it will decide the location for the SKU in the FGI. The logic code is designed to behave as the WMS for the FGI as much as possible. It will first check if there are any matching SKUs with the same Production order ID in the FGI and try to place on top without exceeding the height constraint. The virtual Put-away activity is visualized in Figure 35, where the height constraint is not reached.

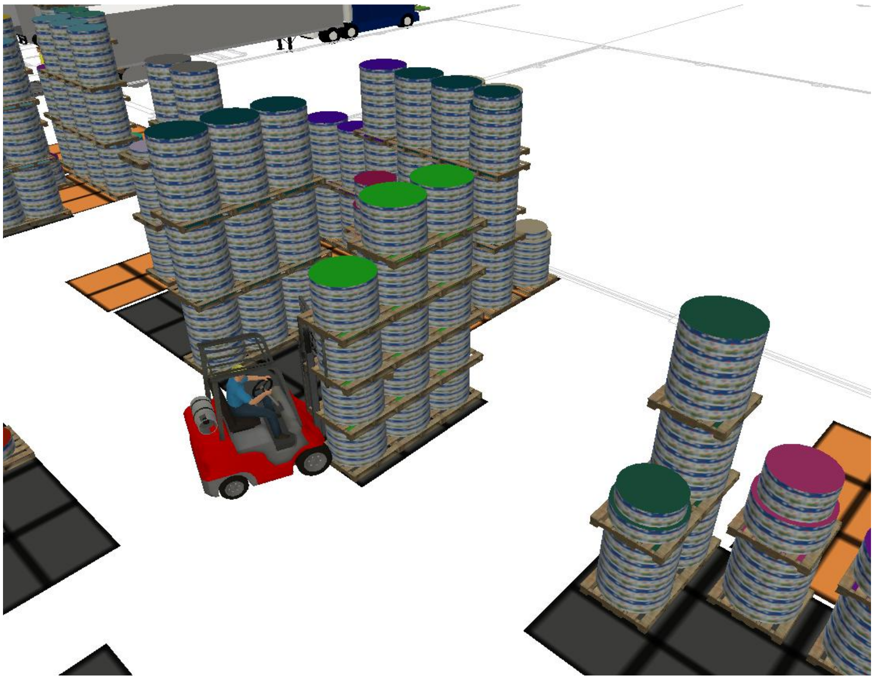

Figure 35: Put-away a SKU in a stack

No mixing of the production orders is allowed at the same pallet position. If the height constraint is reached, the logic code checks if the SKU can be placed in front of the matching SKUs. If not, the SKU is placed in an empty bin or the bin with most available pallet positions. If there is no matching order or there is no pallet position

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[4] In a triangular distribution the first value is the minimum time, the second value is the most common time and the third value is the maximum time.

nearby, it will first check if there is an empty bin to place the SKU in. If there is no empty bin, it will place the SKU in the bin with most empty pallet positions. The total height of a stack cannot be higher than 5300 mm. The top reel diameter cannot be smaller than 975 mm if stacking should be allowed. The unloading sequence will be a mean of the time it takes for unloading at different heights. When the FGI becomes full, the arriving SKUs will stay on the conveyor belt until there is an available pallet position. After a put-away, the forklift returns to the receiving area. An assumption is made due to the order size. The model does not take the order size in consideration when suggesting a pallet position.

Picking: Historical data of the picking orders will be used which will generate an event. One forklift driver has been removed from Shift 1 and Shift 3 due to unrelated work activities of the picking process. The forklift driver is told to drive to a specific location and pick up the ordered SKU. If another forklift is blocking the way by picking or put-away activities, the last arriving forklift has to wait until the first forklift is finished with the put-away or picking. This will be modelled by a temporarily block that will be set on the bin for the other forklift drivers.

When a picking list arrives, it is possible that the SKUs which are included in the picking list are blocked by other SKUs. If this would happen, the blocking SKUs must be relocated somewhere else in the FGI. The picking list arrives to the queue in front of the truck. At the same time as the picking order enters the queue, the logic code for the queue starts and checks if there are any SKUs in the FGI with the same production order ID as on the picking list. If a SKU with the same production order ID is found, the logic code checks if there is any SKU in front of the ordered SKU. If there is a SKU blocking, another logic code starts which is similar to the logic for the putaway activity. It will first check if there are other SKUs with the same production order ID as the blocking SKU. If so, the blocking SKU will be placed there. If there are no similar SKUs, the blocking SKU will be placed in an empty bin or in the bin with most empty pallet positions. When the SKU is relocated, it sends a message to the truck and triggers a logic code to check if there are more SKUs blocking the SKU which is to be picked. In the relocation process, the height and top reel diameter constraint are taken in consideration as well. This process goes on until all the blocking SKUs are relocated and the ordered SKU can be picked. Virtual blocking SKUs can be seen in Figure 36.

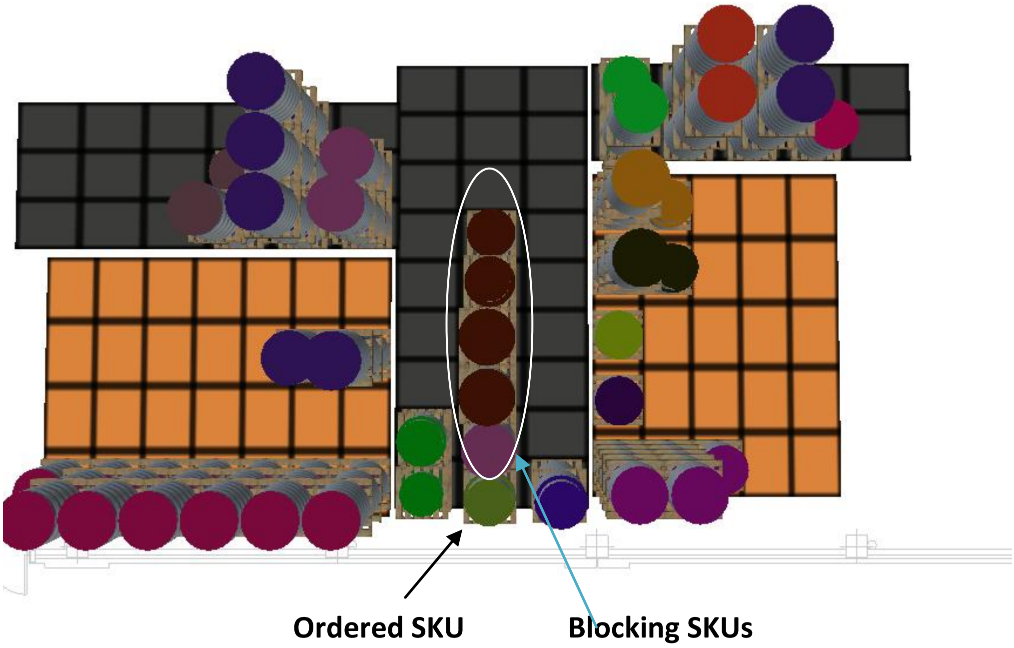


Figure 36: Blocking SKUs when picking ordered SKU

When the forklift picks up the blocking SKU for relocation, the current bin will be blocked so no other forklift can place other SKUs in that bin. When all SKUs have been relocated, the ordered SKUs can be picked. A label is put on the floor storage zone meanwhile the forklift is relocating a SKU. The logic code for relocating is programmed to compare the suggested bin for relocating a SKU to the label on the floor storage zone. If there is no match, the SKU can be placed in that bin.

Loading: Once a SKU is picked, it is transported and unloaded in the loading area. The SKU is placed in a FIFO queue at the correct loading dock. During 08.00-20.00, there is one person, or resource, for each loading dock simulating the truck driver. Containers will not be part of the model since no historical data regarding the arrival frequency have been received.

Loading time for a trailer is shown in Table 11.

Load carrier	Capacity (SKU)	Loading time (min)
Trailer	22	20-40

Table 11: Loading Data

No pallet truck will be part of the model since it is considered having walking speed of 1.4 m/s which is the same speed as the human resource (Preferred walking speed, 2012). The two truckloads that are pre-staged during 20.00-23.50 will not be performed in the model. Instead the picking and loading will start earlier in the morning to compensate. Once a picking list has been completed, there will be a delay for the next picking order to arrive. Since the trucks are assumed to arrive independently of each other, the arrivals can be assumed to follow a Poisson process with an exponential inter-arrival time (Marklund and Laguna, 2005). This will symbolize the undocking and exit of the current truck and enter and docking of the waiting truck. No loading of additional material will be included in the model. The loading process is illustrated in Figure 37.

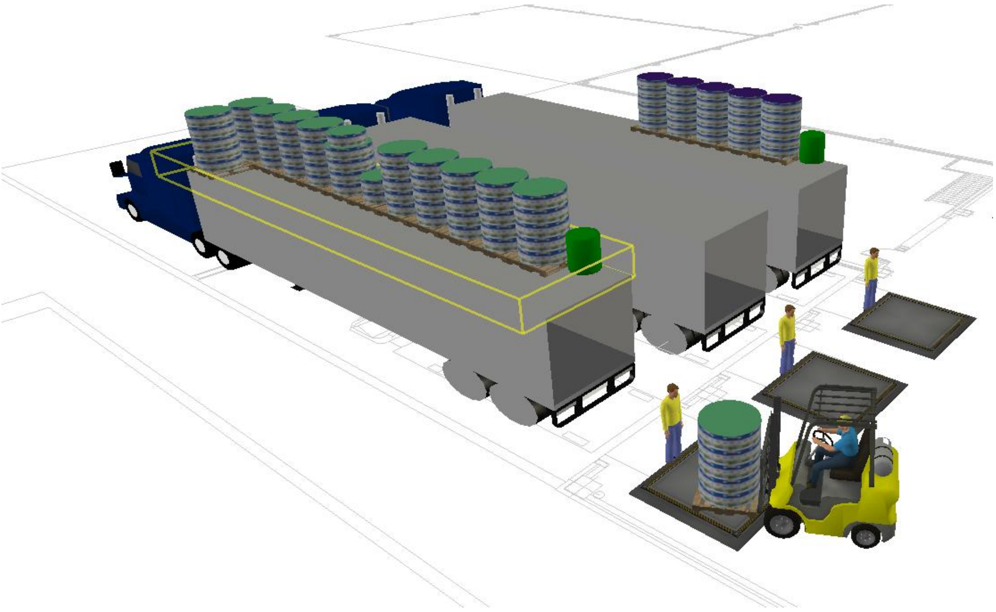


Figure 37: Loading of SKUs on trailers at the loading docks

5.2.1 Arrival SKU Process

There are many events which can occur and decisions that are made during the arrival process. Figure 38 is a detailed flow chart of the events in reality related to the arrival process of a SKU. The arrival process in the model is mainly based on these events and decisions. A detailed description of the decisions and events in the flow chart is given:

Start: SKU enters the pick point of the Finishing Area
1. Available AGV?
    Yes: AGV prepares to pick SKU
    No: Add one SKU to a queue
        Wait until an AGV is available.
        AGV prepares to pick SKU
2. AGV picks SKU
3. AGV transports the SKU to the receiving conveyor belt of the FGI
4. Another AGV unloads on the Receiving conveyor belt?
    Yes: AGV is placed in a FIFO queue
        Wait until the other AGV has unloaded.
        AGV prepares for unloading on the receiving conveyor belt
    No: AGV prepares for unloading on the receiving conveyor belt
5. AGV checks if conveyor belt is full
6. Is the conveyor belt full?
    Yes: AGV waits until there is an empty slot on the conveyor belt to unload the SKU
    No: AGV unloads the SKU on the conveyor belt
7. SKU is located on the conveyor belt
8. Conveyor belt starts to transport the SKU
9. Any other SKU on the conveyor belt?
    Yes: SKU is transported on the conveyor belt to the preceding SKU. FIFO queue is created
    No: SKU is transported to the pick point at the end of the conveyor belt
10. SKU reaches the pick point at the end of the conveyor belt
11. Is there an available forklift?
    Yes: forklift driver prepares to pick and scan the SKU
    No: SKU waits at the pick point until there is an available forklift
        Forklift prepares to pick and scan
12. Forklift driver picks and scans the SKU
13. First SKU in an order?
    Yes: Forklift driver transports the SKU to the suggested bin by the WMS-system
    14a. Forklift driver arrives to the suggested bin
    15a. Bin size appropriate?

Yes: SKU placed in the suggested bin

END

No: Appropriate bin is manually chosen by the forklift driver.

No: Forklift driver transports the SKU to the pre-chosen bin

14b. Forklift driver arrives at the bin

15b. Is the bin full?

Yes: Forklift driver chooses to place the SKU in the closest available bin

16. Forklift driver places the SKU in the bin

No: Forklift driver places the SKU in the bin

END

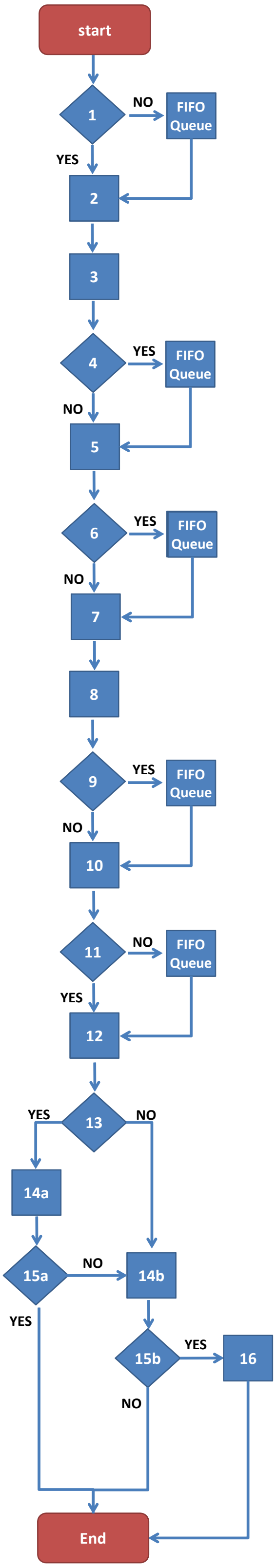


Figure 38: Arrival Process

5.2.2 Departure SKU Process

Figure 39 is a detailed flow chart of the events related to the departure process in reality of a SKU. The departure process in the model is mainly based on these decisions and events. Each step is described in detail:

Start: The forklift driver gets a picking list.
1. The forklift driver drives to the bin according to picking list.
2. Are there some other forklift picking SKUs that prevent his transportation?
    YES: The forklift driver will have to wait until the other forklift is finished.
        The transport continues
    NO: The forklift driver continues his transport.
3. Forklift driver arrives at the bin according to picking list
4. Is there some other SKU that block the chosen SKU from picking?
    YES: The forklift driver scans and removes the blocking SKU and places it in a near bin
        (This activity is repeated until the first condition is false)
    NO: He scans and picks up the SKU
5. Forklift driver transport the SKU to the loading area.
6. Are there some other forklift picking SKUs that prevent his transportation?
    YES: The forklift driver will have to wait until the other forklift is finished.
    NO: The forklift driver continues his transport.
7. SKU arrives in the loading area
8. Are there anything blocking the unloading in the loading area?
    YES: The forklift driver waits until unloading is possible
        Forklift driver places the SKU in the loading area
    NO: Forklift driver places the SKU in the loading area
9. SKU is placed in the loading area
10. Is the shipping associated with a container?
    YES: Another Company forklift driver picks the SKU with a pallet truck and transports it to the container
    11a. SKU is placed in a container.
        END
    NO: The truck driver picks up the SKU with a pallet truck and transports the SKU to the trailer.
    11b. SKU is placed in trailer.
        END

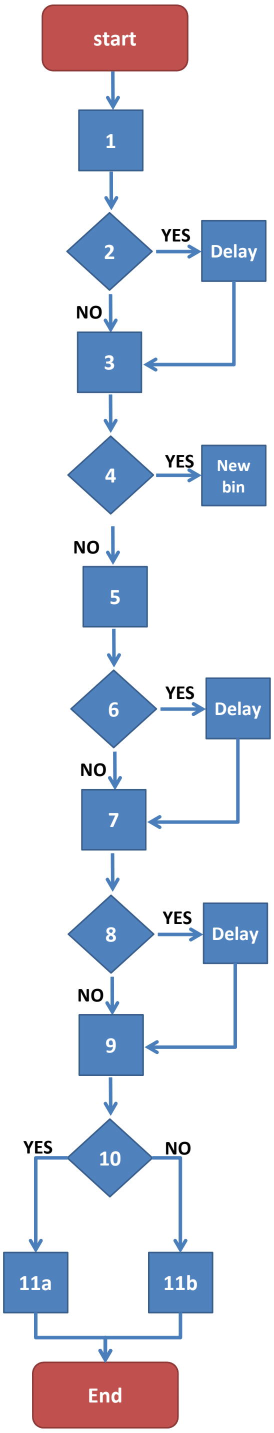


Figure 39: Departure Process

5.3 Transporters

AGV: In the simulation model of the current system, there will be a pool of 3 AGVs which only operates the transport of SKUs to the FGI. The times have been identified for the AGVs by observations, which are used in the model and are shown in Table 12.

Activities	
Loading	45sec
Speed	1 m/s
Unloading	85 sec

Table 12: AGV activities

The picking and unloading times are considered constant due to the automatic procedure of the AGVs. No Mean Time Between Failure (MTBF) has been able to be retrieved. Therefore, no MTBF will be used in the model. Figure 40 visualizes a virtual AGV.

Figure 40: AGV with SKU

Forklifts: There is a total pool of 5 forklifts operating with respect to the shift schedules. Two forklifts are always operating in the receiving team and 0-3 operating in the picking team. The time for transportation is depending mostly on the distance to the bin. However, the speed of a forklift will also have its affect on the transportation time. The top speed is set to 3 m/s. There is no MTBF set on the forklifts. Loading and unloading times follows a triangular distribution received by observations can be seen in Table 13.

Activities	**sec**
Loading	[8,26,16]
Speed	3 m/s
Unloading	[7,23,13]

Table 13: Activities Picking team

The forklift drivers are scheduled to one hour break per day, shown in Table 14.

Breaks	
Break 1	30 min
Break 2	10 min
Break 3	10 min
Break 4	10 min

Table 14:Breaks

The forklift drivers are overlapping their breaks so that there are always forklift drivers operating in the FGI.

The receiving forklifts schedule is illustrated in Table 15.

Working hours Receiving team	**Monday - Sunday**
Shift 1: 2 forklift drivers	07.50 – 15.50
Shift 2: 2 forklift drivers	15.50 – 23.50
Shift 3: 2 forklift drivers	23.50 – 07.50

Table 15: Shift Receiving Team

The picking forklifts schedule is illustrated in Table 16.

Working hours Picking team	**Monday - Friday**
Shift 1: 2 forklift drivers	07.50 – 15.50
Shift 2: 1 forklift driver	11.00 – 19.00
Shift 3: 1 forklift driver	15.50 – 23.50

Table 16: Shifts for Picking Team

5.4 Input Data & Response

5.4.1SKU Cost

The costs for a SKU in the FGI can be seen in Table 17 (Escrich, 2012).

SKU costs	
Handling Cost	15,7 €/SKU
Holding Cost	0,9 €/day

Table 17: SKU costs

5.4.2 Data for Arriving SKUs

The generated data that are used in the model consists of eight days of arriving SKUs. Since there is no production in the slitting machine during the weekend and no trucks will be loaded either, the weekend has no effect on the FGI. The data consists of in total 6 days of production which will be replicated to always supply the FGI during longer runs. This means that after six days in the run, the seventh day of arriving SKUs will actually be day one again. Figure 41 is a chart of the arriving SKUs measured between the times 00.00 to 23.59.

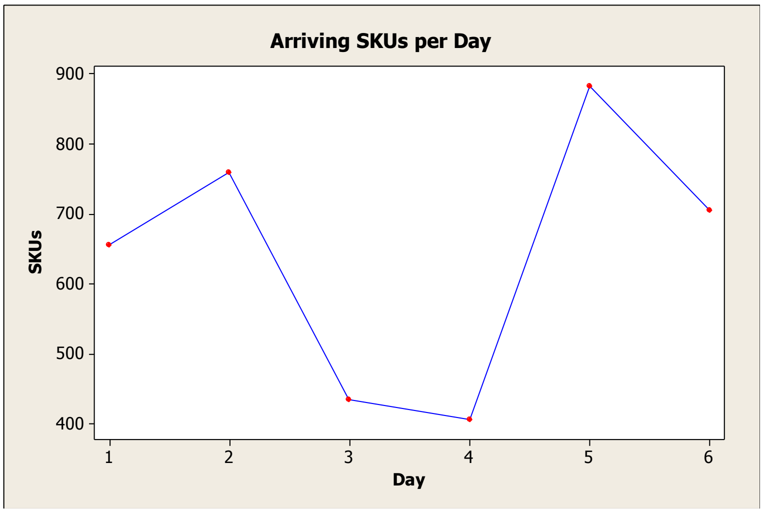


Figure 41: Arriving SKUs per Day

5.4.3 Data for Departing SKUs

The departure data is based on historical raw data from 2011. The picking orders have been sorted to match the generated arriving SKUs. For example, in the beginning of 2011, SKUs which have been produced in 2010 can be picked. However, the generated data only consists of SKUs produced in 2011. Therefore, these picking orders have been removed from the data and replaced with picking orders where

SKUs exists. The data will be replicated to be able to perform longer runs. Relevant information for the departure data consists of Picking Order ID, amount of SKUs to be picked, production order ID etc. (see Appendix III). The amount of departed SKUs per day according to 100 days historical data are shown in Figure 42.

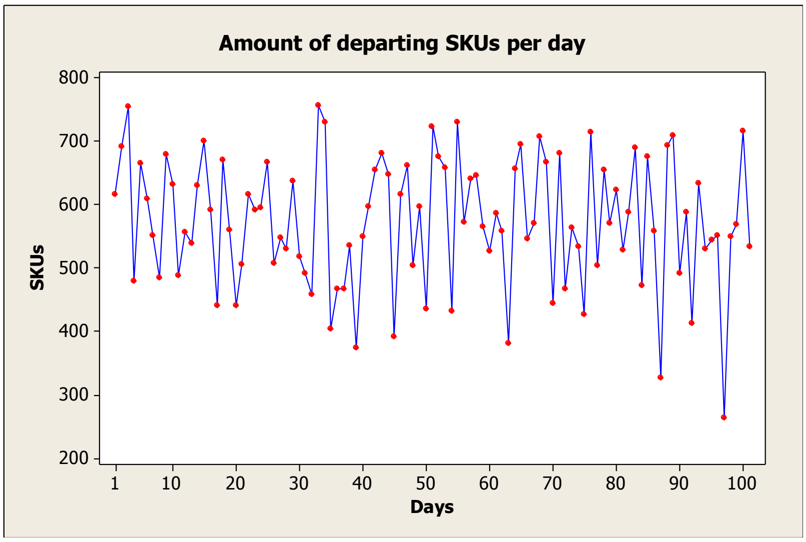


Figure 42: Amount of Departing SKUs per Day

The average departed SKUs per day is 573 and the peak is around 750 SKUs. The amount of SKUs shipped each day from the FGI follows a normal distribution which can be seen in Figure 43.

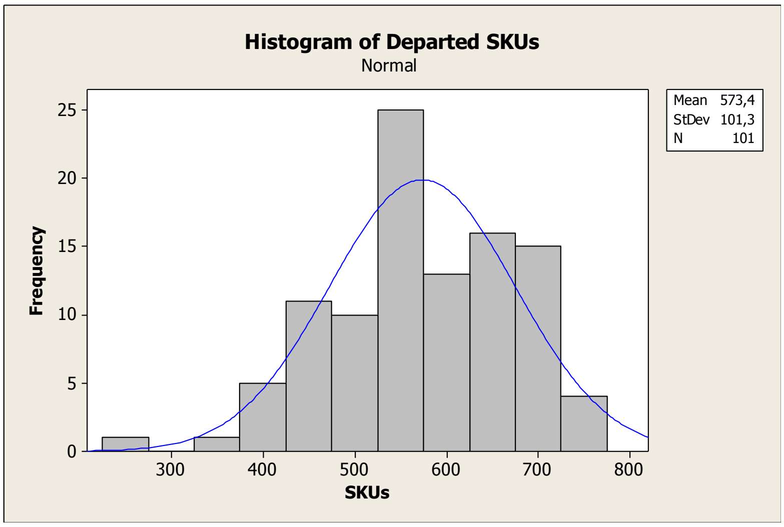


Figure 43: Histogram departing SKUs

There is a not always clear correlation between the amount of departing trucks and the departing SKUs. The reason is that not all trucks are fully loaded. 100 days of trucks departing from the FGI has been plotted in Figure 44.

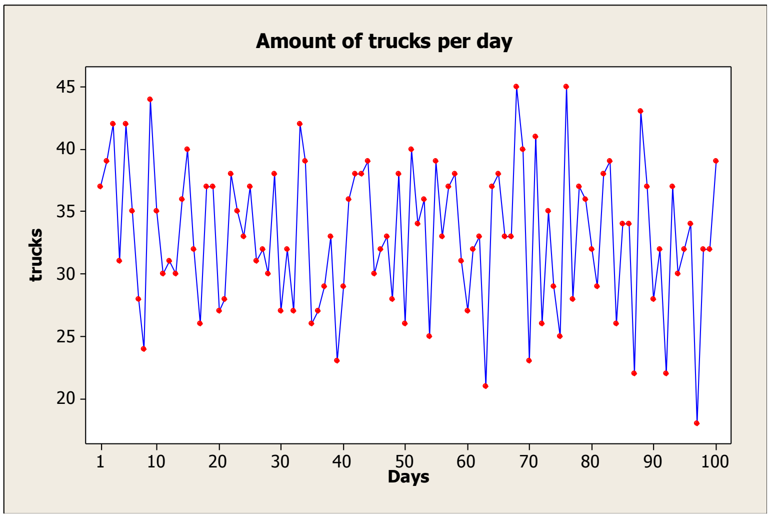


Figure 44: Amount of trucks per day

The distribution for the amount of trucks per day is shown in Figure 45. The Weibull distribution is the most appropriate distribution, see curve in Figure 45.

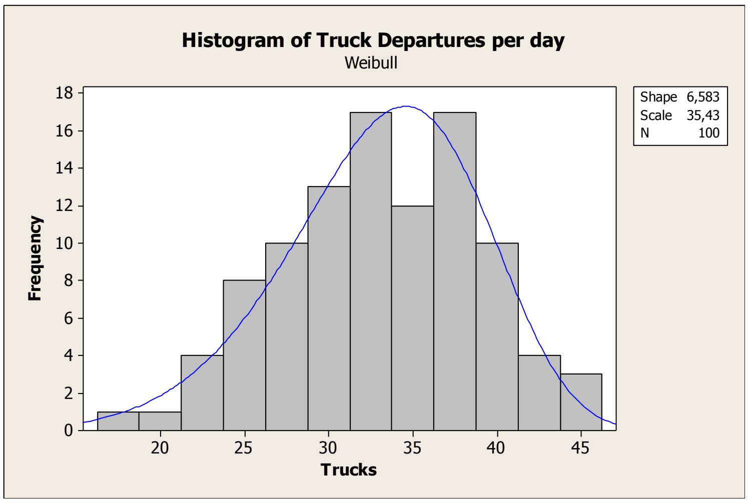


Figure 45: Histogram Truck departure

5.4.4 Response

Before the model is being developed, it is important to know what kind of response that is wanted. Since this model has the purpose to improve the FGI with respect to the life-cycle cost, the response must contain information which can be related to a cost. Throughput is an important parameter which will be measured as SKUs per day. Travel distance for the forklifts another important parameter since the longer it has travelled over a specific set of time, the fewer amounts of SKUs will be delivered. There is also a direct cost when the forklift driver is using the forklift. Since relocating SKUs is a double handling, it has no value added. Therefore, the amount of SKUs that have been relocated will also be measured. Finally, average inventory level is measured per day which gives the utilization of the FGI and can be connected to the holding cost.

5.5 Simulation Run

5.5.1Warm-up

The real FGI in reality is never fully depleted; there are always SKUs in stock. In the simulation model the FGI will start completely empty and continuously replenished throughout the week. For that reason, the simulation model will have a warm-up time, meaning that the recording of data does not start at the beginning of the simulation. Instead, the recording of data will start after three days of activity in the FGI.

5.5.2 Length and Number of Runs

A run is the time the model is used, for example on run can be one week, one year or just one day. The number of runs largely depends on the computational capability. More runs mean additional time for each experiment but will also give a more statistically reliable result. When analyzing the original model, the number of runs has been set to 6 and each run is 10 days long where the warm-up time is 3 of those days. This means that there will be 7 days of recorded statistics from the model. The simulation starts at 08.00 in Monday morning, so one day in the simulation is from 08.00 to 07.59 the day after. The reason is that at 07.59, the maximum number of SKUs will be in the FGI due to the fact that no shipping activities have occurred for 12 hours.

5.5.3 Simulation Response

Arriving SKUs

The arriving SKUs per day are the same for each run due to the historical data generating the SKUs in combination with no dynamic of the AGVs. Furthermore, the difference between the chart in Figure 46 and the chart in Figure 41, can be explained by the simulation time; 08.00 to 07.59 compared to the generated input data where the Arriving data is logged 00.00-23.59.

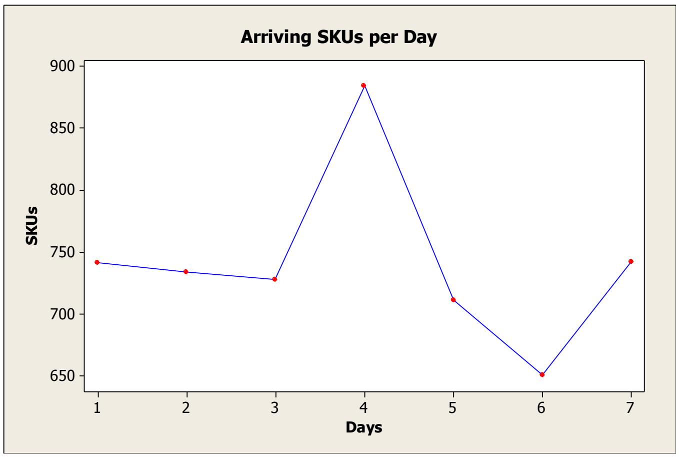


Figure 46: Arriving SKUs in Simulation

Throughput

The throughput is measured at the end of one day in the simulation; at 07.59. Figure 47 shows a chart with the average throughput per day.

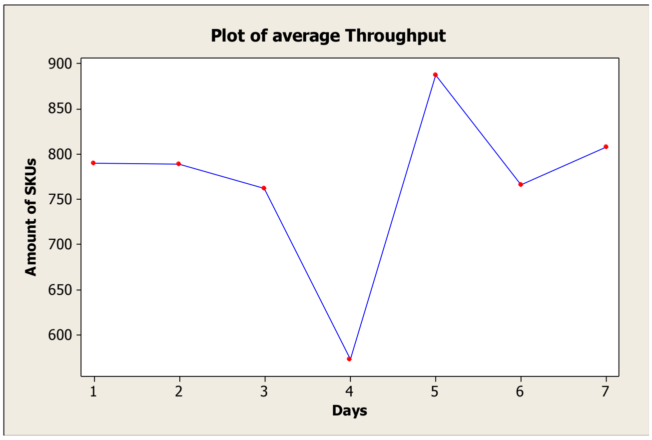


Figure 47: Average throughput/day

Inventory Level

The value at day 1 is recorded at 08.00; when simulation starts to record data. The average inventory level can be seen in Figure 48.

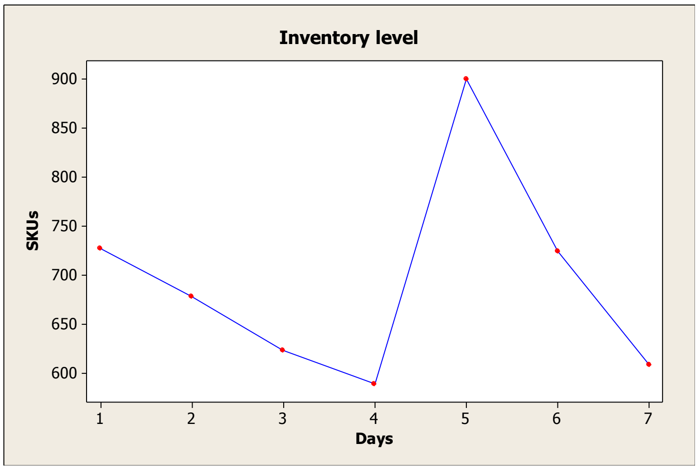


Figure 48: Inventory level for original layout

Performance Parameters

All measured performance parameters can be seen in Table 18.

OriginalLayout	Average inventory level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
mean	**717**	**658**	**55304**	**5333**	**825585**	**5211**
confidence		579-737	52238-58370	5271-5395	817657-833513	0
Std dev		75	2921	59	7553	0
min		558	50480	5264	818470	5211
max		773	58999	5394	838360	5211
inventory level						
N=6						

Table 18: Performance parameters

Calculated Cost for the Original Layout

The measured cost for the original Layout is presented in Table 19. See Appendix IV for detailed calculations.

Annual measured cost	**371961€**
Annual relocation cost	**92250€**
Annual travelling cost	**176461€**
Annual holding cost	**103250€**

Table 19: Costs Original layout

5.5.4 Validation

The validation of the original model is have been made in three different ways, Face Validation, Extreme Condition Test and Turing Test. The validation methods are explained in Chapter 2.

Extreme Condition Test

Comparing the result of the Extreme Conditions test with the response from the original model is seen in Table 20.

	Average Inventory Level	**Number of relocations (95%)**	**Average stay time in racks (95%) (s)**	**Through-put Total (95%)**	**Forklift average total distance (95%) (m)**
Original Model	717	658	55304	**5333**	**825585**
Extreme Condition	**145**	**7,1**	**16567**	5323	1052473

Table 20: Original Model vs. Extreme Conditions

The number of relocations average stay time has decreased significantly as predicted. This can be explained by during this test all the limitations were removed and all the SKUs that entered the warehouse was almost directly picked and shipped when a complete order was located in the warehouse. The forklift distance increased due to when the warehouse is empty, the arriving pallets are placed closest to the receiving conveyor and the forklift have to drive a longer way in general to pick up the SKUs when starting at the loading bay area. The throughput will remain the same since the frequency of the arriving SKUs is unchanged. The result showed that the system behaved as it should when all the limitations was removed.

Turing Test

The result from the Turing Test is presented in Figure 49. The model response is much higher than the real output. The input data for the arriving SKUs has a high frequency, which forces the model to extract SKUs with the same the frequency. If not, the FGI will be overloaded. In addition, real input data for the arriving SKUs would give a much more credible result. The conclusion regarding the result from the Turing Test is that it could either be the input data that is inaccurate or the model itself.

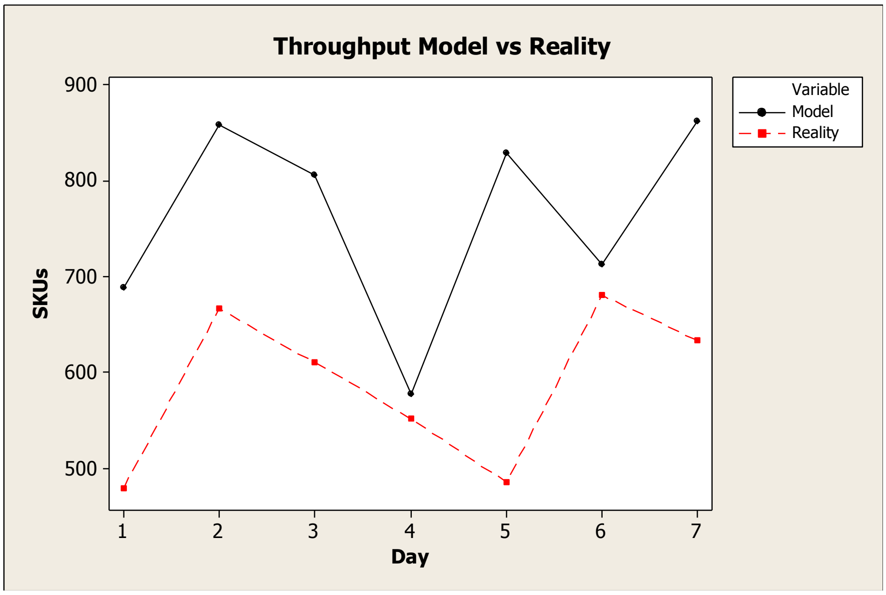


Figure 49: Turing Test

5.6 Experimental Design

To be able to find an improved layout of the FGI, different scenarios have been created. Once the simulation model has been verified and validated, it can easily be modified to fit the scenarios where the possible improvements are included. In the model, a large amount of parameters can be changed such as amount of forklifts, amount of loading docks, location of pallet positions etc. A main objective is to avoid any cost for implementing the improvements. However, if the improvement has a cost, it could be considered if the total life-cycle cost is reduced compared to the original layout.

5.6.1 Modelled Scenarios

A set of scenarios have been created through discussion and brainstorming. Thereafter, additional scenarios have been created by combining successful experiments to evaluate if further improvements can be made. After discussions with parts of the warehouse management in Arganda, the most relevant scenarios have been evaluated.

Scenario 1: Add one loading dock

By adding a loading dock, four trailers can be loaded at the same time. By doing so, the expected result is to reduce the inventory level and decrease the number of relocations.

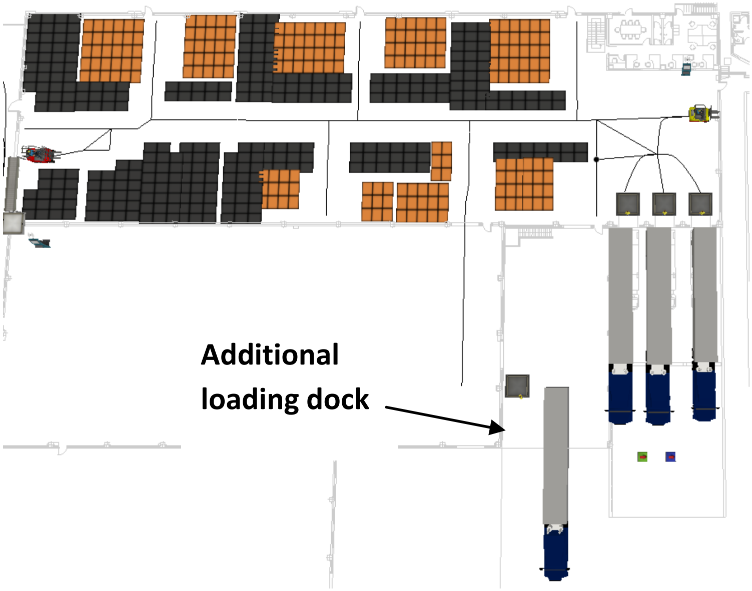


Figure 50: Scenario 1

Scenario 2: Optimum bin size, 6 pallet positions

This experiment has the purpose to see if it is more efficient in some way to use a standard size for each bin. The most space efficient bin size was found by using the formula in Equation 1. See Appendix IV for calculations. The result from entering all variables into the formula gave that the most space efficient bin depth was six pallet positions deep. The layout for the FGI was changed and all the bins were given the size of six pallet positions. The trade-off by this change is that the total SKU capacity decreased to 1443 from 1554, but hopefully it would bring some savings by decreasing the double handling in the FGI and the travelling distance.

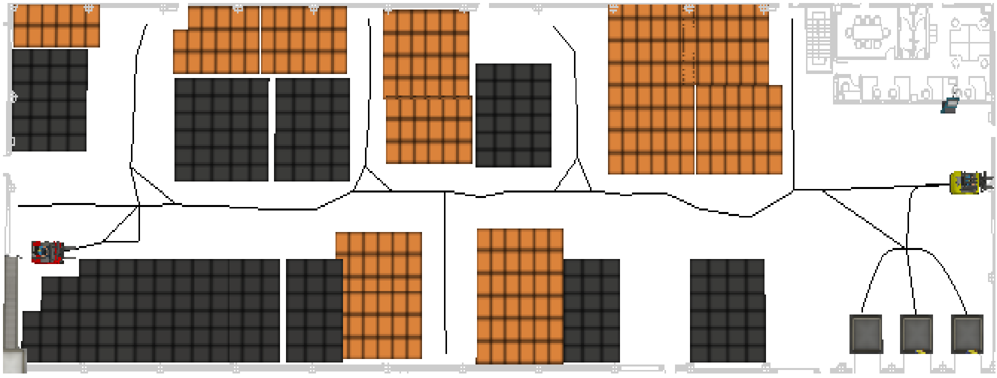


Figure 51: Scenario 2

Scenario 3: Vertical Rack

A small pallet shelf was installed as seen in Figure 52. The capacity of the FGI decreased with 37 possible locations by implementing this shelf. The loss of capacity might not be of big importance due to hopefully other savings such as less relocation and maybe a better put-away policy.

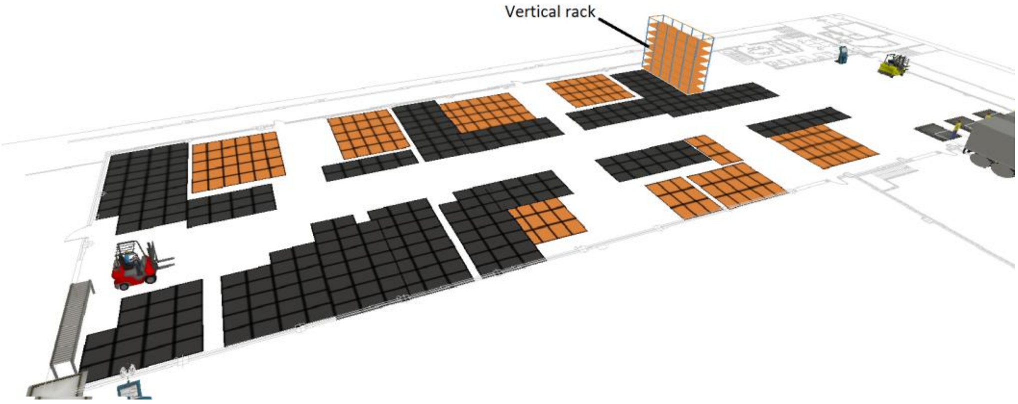


Figure 52: Scenario 3

Scenario 4: Add one loading dock and forklift

This experiment is the same as scenario 1 except that one extra forklift is added to the picking team. The additional forklift will be put on the picking overlap schedule.

Scenario 5: High Capacity Layout

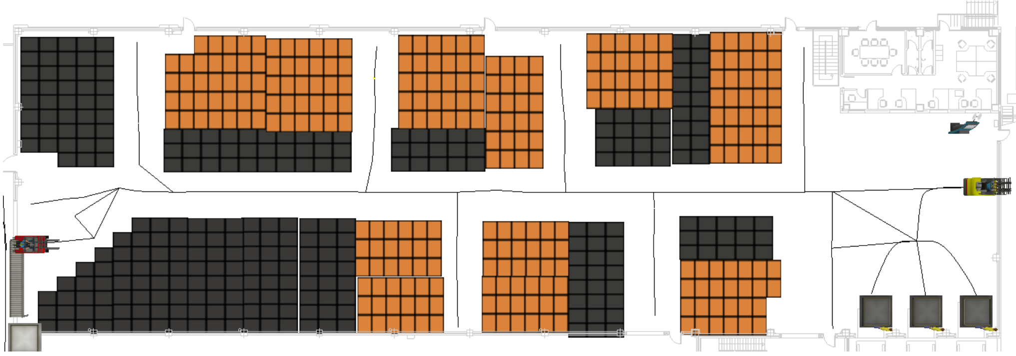


Figure 53: Scenario 5

The layout in this experiment has been taken to its limit due to pallet positions. The SKU capacity has increased to 1668 from 1554 because of additional pallet positions. The interesting part will be to see if the extra pallet positions will decrease the relocations.

6. Results & Discussion

This chapter contains the results from the simulation runs of the different scenarios. The results of each scenario will be analyzed, evaluated and discussed.

The results will be based on the response from the simulations runs of the different scenarios. For more accurate result, it is necessary to do more than one run. When all the runs for the different scenarios are done, it is possible to compare the results to each other.

6.1 Scenario 1: Add one loading dock

This scenario has been under discussion among the members of the Warehouse Management. During the peak hours at the middle of the day, the loading of the trucks becomes a bottleneck. By adding a loading dock, the expected result was that the average inventory level should decrease. The measured performance parameters for scenario 1 are presented in detail in Appendix IV.

The model managed the picking orders much more efficient with the result of smaller picking order queues. Comparison of the original model and the model with an additional loading bay is seen in Table 21. A majority of the performance parameters have been improved. The *average inventory level* has decreased by 12 % which is a direct result of the significant decrease of *average stay time* in the inventory of 34 %. The reason is could be because more trucks can be loaded in the FGI at the same time and the picking activity can be started faster. The *Number of Relocation*-parameter has also been decreased significantly. The reason could be because of lower inventory level. Lower inventory level results in less mixed orders in each bin. The *Forklift average total distance*-parameter has increased. The reason is explained by the longer distance to reach the additional loading dock. The forklift has to drive through the Additional Material inventory, to reach the loading dock.

	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Original Model	717	658	55304	5333	825585
Scenario 1	632	451	36511	5234	861494
Percentage Change	-12%	-31%	-34%	-2%	4%

Table 21: Comparison Scenario 1 vs. Original Model

The annual costs for Scenario 1 can be seen in Table 22. The annual relocation cost has decreased compared to the Original Model due to the lower number of relocations. The annual holding cost has also decreased due to the lower inventory level in Scenario 1. The travelling cost has increased due to the longer distance to reach the additional loading dock. No investment cost has to be made since the trailers can be loaded from the side directly from ground level instead of docking to a "real" loading dock.

Annual measured cost	**329324 €**
Annual relocation cost	**63250€**
Annual Holding Cost	**59750€**
Annual Travelling Cost	**206324€**
Investment Cost	**0€**

Table 22: Costs for Scenario 1

Comparison of the annual cost of the Original Model and Scenario 1 can be seen in Table 23. The annual measured cost has been reduced with approximately 43000€. By implementing this scenario, the life-cycle cost of the packaging material will be affected in a positive direction.

Annual measured cost

Original Model	**371961€**
Scenario 1	**329324€**
Difference	**-42637€**

Table 23: Comparison Original Model vs. Scenario 1

6.2 Scenario 2: Optimum bin size: 6 pallet positions

Since the average order size is constantly getting smaller for each year, the bin sizes in the FGI are not up to date. The best average bin size with respect to the average order size in the generated input data has been calculated. Thereafter, the bin size was implemented for all bins. The expectation was to lower the amount of relocations. In this scenario, the bin size was set to 6 pallet positions. See Appendix IV for detailed results of the performance parameters and calculations.

A comparison of the Original Model and Scenario 2 is presented in Table 24. The experiment had a mixed result. The inventory level decreased with 4 % and the average stay time decreased with 10% which will affect the holding cost in a positive way. However, the amount of relocations increased substantially. The reason for the result in this experiment was probably the reduced FGI capacity. Due to the capacity, the forklift was given less alternatives to store the SKUs and therefore, more relocations were necessary. Because relocations become more common, it is obvious that the forklifts need to drive a longer way when there is much unnecessary driving to relocate blocking SKUs. It was also noticeable that the experiment started to fail if the warehouse capacity reached over 800 SKUs. The relocations were too time consuming, so the FGI started to be overfull after some time.

	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Original Model	717	658	55304	5333	825585
Scenario 2	686	771	49572	5375	868766
Percentage Change	-4%	17%	-10%	1%	5%

Table 24: Comparison Scenario 2 vs. Original Model

The annual costs for Scenario 2 can be seen in Table 25. The increased level of relocation became too big to be able to gain any benefits. The relocation cost has increased compared to the original model. The travelling cost has also increased due to the longer distance the forklifts have travelled. The main improvement has been the reduction of the annual holding cost due to lower time each SKU spend in the FGI.

Annual measured cost	**385742€**
Annual relocation cost	**108250€**
Annual Holding Cost	**88500€**
Annual Travelling Cost	**188992€**
Investment Cost	**0€**

Table 25: Costs for scenario 2

Comparing the annual measured cost for Scenario 2 and the original model can be seen in Table 26. Compared to the original model, Scenario 2 is not to be recommended for implementation. The result shows that it would be more expensive to implement this layout than keeping the original layout. There is an increased annual cost with 14000€ which will affect the life-cycle cost of the packaging material in a negative direction.

Annual measured cost

Original Model	371961€
Scenario 2	385742€
Difference	**13781€**

Table 26: Comparison Original Model vs. Scenario 2

6.3 Scenario 3: Vertical Rack

The managers of the warehouse in Arganda have discussed an installation of a vertical rack for smaller SKUs with only two or three reels on. The expectations for this scenario were that the removal of the small SKUs from the floor storage would give more space for the higher SKUs and to utilize the space better in the FGI. See Appendix IV for detailed results of the performance parameters.

A comparison of the Original Model and Scenario 3 is presented in Table 27. The result of the comparison is that Scenario 3 is an overall a worse alternative than the Original Model. All performance parameters have increased and especially the amount of relocations. The relocations increased in this experiment with 80 %. The reason for the substantial increase of relocation could depend on the loss of pallet positions due to the instalment of the rack. Also, the forklifts are needed to drive a longer way when relocating smaller SKUs. Due to this matter, the receiving forklifts will be able to fill up the FGI more compared to what is shipped. By this, a negative trend starts and the inventory level will increase. It is only natural that the average stay time increase together with the number of relocations and higher inventory levels as well, because the time is spend on relocating SKUs instead of picking them. Another explanation for the substantial amount of relocation could be a logic error but it could not be confirmed.

	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Original Model	717	658	55304	5333	825585
Scenario 3	797	1184	60578	5310	841905
Percentage Change	11%	80%	10%	0%	2%

Table 27: Comparison Scenario 3 vs. Original Model

The annual costs and investment cost for Scenario 3 can be seen in Table 28. The annual relocation cost has increased dramatically compared to the original model due to the higher number of relocations. The annual holding cost has also increased due to the larger average inventory level. The travelling cost has also increased since the orders have to be separated into small SKUs and large SKUs.

Annual measured cost	**460531€**
Annual relocation cost	**166250€**
Annual Holding Cost	**125750€**
Annual Travelling Cost	**170031€**
Investment Cost Year 1	**1500€**

Table 28: Costs for Scenario 3

Comparing the annual measured cost for Scenario 3 and the original model can be seen in Table 29. The comparison of the Original model and Scenario 3 clearly shows that Scenario 3 will increase the life-cycle cost of the packaging material. Therefore, the scenario is not recommended.

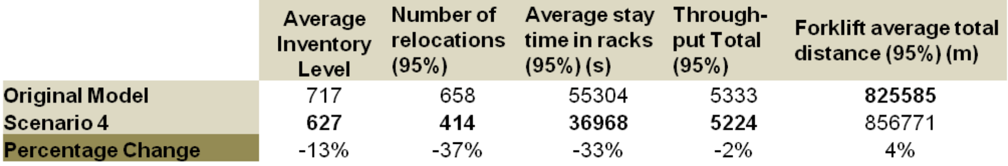
	Annual measured cost
Original Model	371961€
Scenario 3	460531€
Difference	**88570€**

Table 29: Comparison Original Model vs. Scenario 3

6.4 Scenario 4: Add one loading dock and forklift

This scenario was created to see of there could be any further improvements compared to Scenario 1. One of the main disadvantages is that this experiment involves a new resource which will add a cost. See Appendix IV for detailed results of the performance parameters.

First of all, a comparison of the Original model and Scenario 4 was made. The result is presented in Table 30. All performance parameters have been improved except the *Forklift average total distance* for the picking forklifts. The *average inventory level* has decreased by 13 % which is a direct result of the significant decrease of *average stay time* in the inventory of 37 %. The reason is could be because more trucks can be loaded in the FGI at the same time and the picking activity can be started faster. The *Number of Relocation*-parameter has also been decreased significantly. The reason could be because of lower inventory level. Lower inventory level results in less mixed orders in each bin. The *Forklift average total distance*-parameter has increased. The reason is explained by the longer distance to reach the additional loading dock. The forklift has to drive through the Additional Material inventory, to reach the loading dock.



	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Original Model	717	658	55304	5333	**825585**
Scenario 4	**627**	**414**	**36968**	**5224**	856771
Percentage Change	-13%	-37%	-33%	-2%	4%

Table 30: Scenario 4 vs. Original Model

The annual costs and investment cost for Scenario 4 can be seen in Table 31. The relocation cost has decreased significantly which can be explained by the lower average inventory level. By having a lower average inventory level, less SKUs have to be relocated due to mixed orders in the bins. The decreased average stay time in the FGI in a combination with the decreased average inventory level contributes to the substantially lower holding cost compared to the original model. However, there are additional cost compared to the original model; The salary of a forklift driver and the rental of a forklift. The annual rental cost of a forklift has been estimated to 5000€. As in Scenario 1, there is no investment cost since the trailers can be loaded from the side at ground level. No actual platform has to be built.

Annual measured cost	**359620€**
Annual relocation cost	**51807€**
Annual Holding Cost	**60250€**
Annual Travelling Cost	**206163€**
Annual Forklift driver Salary	**36400€**
Annual Rent of Forklift	**5000€**
Investment Cost	**0€**

Table 31: Costs for Scenario 4

Comparing the annual measured cost for Scenario 4 and the Original Model can be seen in Table 32. The comparison of the Original Model and Scenario 4 has a small reduction of annual measured cost of 12000€. This will affect the life-cycle cost of the packaging material in a positive direction. Therefore, Scenario 4 is recommended.

Annual measured cost

Original Model	371961€
Scenario 4	359620€
Difference	**-12341€**

Table 32: Comparison Original Model vs. Scenario 4

In addition, a comparison has been made of Scenario 1 and Scenario 4 to identify the overall best scenario. The result of the comparison of the performance parameters is presented in Table 33. There is no significant difference of the performance parameters between the two scenarios except for the relocation parameter. In scenario 4, the number of relocations has decreased with 8% compared to Scenario 1. The reason is assumed to be associated with the blocked bins in the model when a forklift is either relocating or assigned to pick from a specific bin. If a SKU that will be picked is blocked, the forklift will place the blocking SKUs in another bin. When only using three forklifts, there is a risk of having blocking SKUs placed in front of the SKU which will be picked to the additional truck later on. When having four forklifts, this bin would automatically be blocked so no other SKUs could be placed there.

	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Scenario 1	632	451	**36511**	5234	861494
Scenario 4	**627**	**414**	36968	**5224**	**856771**
Percentage Change	-1%	-8%	1%	0%	-1%

Table 33: Scenario 1 vs. Scenario 4

Comparing the annual measured cost for Scenario 1 and Scenario 4 can be seen in Table 34. The result of the comparison shows that the life-cycle cost for the packaging material will be annually 30000€ lower for Scenario 1 compared to Scenario 4.

Annual measured cost

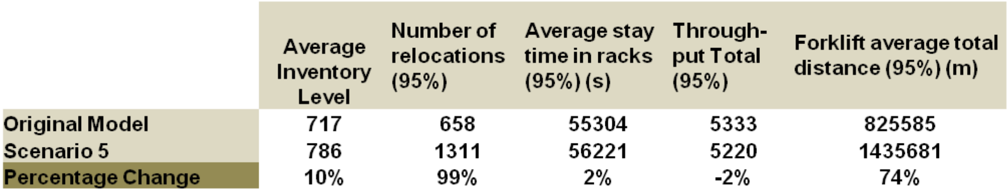
Scenario 1	329324€
Scenario 4	359620€
Difference	**30296€**

Table 34: Comparison Scenario 1 vs. Scenario 4

6.5 Scenario 5: Higher Capacity Layout

This experiment was made because the managers of the warehouse said that one of the main issues in the FGI was the number of relocations and lack of space. By increasing the capacity of the FGI, the expectations were to reduce the number of relocations and lower the inventory level. It is possible that the scenario is a little less employee friendly due to smaller aisles. The trade-off with this scenario will be that it be harder to manage the forklift in the FGI. See Appendix IV for detailed results of the performance parameters.

A comparison of the Original Model and Scenario 5 is presented in Table 35. The result of the comparison is that Scenario 5 is an overall a worse alternative than the Original Model. The average inventory level has increased by 10 %. The relocation is 99% higher than in the original model. The capacity of the FGI is higher, but the bins are made deeper so there is probably a larger mix of orders stored in the same bins than before, which induce the relocations. That is probably the reason for the higher inventory level as well. The total travel distance is 74 % higher in this scenario which affects the usage of the forklifts and lowers the availability.



	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)
Original Model	717	658	55304	5333	825585
Scenario 5	786	1311	56221	5220	1435681
Percentage Change	10%	99%	2%	-2%	74%

Table 35: Comparison Scenario 5 vs. Original Model

The annual costs and investment cost for Scenario 5 can be seen in Table 36. All measured costs have increased compared to the Original Model, especially the travelling cost and the relocation cost. No initial investment has to be made.

Annual measured cost	**799198€**
Annual Relocation cost	**184008€**
Annual Holding Cost	**115000€**
Annual Travelling Cost	**500121€**
Investment Cost	**0€**

Table 36: Cost Scenario 5

Comparing the annual measured cost for Scenario 5 and the Original Model can be seen in Table 37. The comparison of the Original Model and Scenario 5 clearly shows that Scenario 5 would increase the life-cycle cost of the packaging material dramatically compared to the original model if implemented. Therefore, Scenario 5 is not recommended.

	Annual measured cost
Original Model	371961€
Scenario 5	799198€
Difference	**427237€**

Table 37: Comparison Original Model vs. Scenario 5

7. Recommendations & Conclusion

This chapter contains the recommended layout for improved performance of the FGI and the final conclusion of the thesis. Further research will also be presented.

7.1 Recommendations

Once the original simulation model is verified and validated, there are numerous ways to create new scenarios and perform experiments. Five different scenarios have been evaluated with a wide range of results. Some of the scenarios perform better than the original simulation model and some of the scenarios perform worse. Each scenario has been thoroughly discussed and performance parameters as well as costs must be taken into account when choosing the final recommended layout. The result from the different scenarios can be seen in Figure 54. The result from the comparison shows that only Scenario 1 and Scenario 4 would decrease the annual cost for the FGI in Arganda and in a wider perspective decrease the life-cycle cost of the packaging material. The only difference between the two scenarios is an additional forklift in Scenario 4. By adding an additional forklift, there will be additional annual cost due to the forklift and the forklift driver. The only significant difference between the performance parameters of the two scenarios is the relocation parameter. Even if the relocation parameter was reduced with 8 % when adding a forklift, the savings in relocation cost will not be as large as the cost to implement the additional forklift and driver. The savings in relocation cost is roughly 5 000 €, compared to the annual cost of a forklift driver of 36 400 €. The final conclusion is that a new loading dock should be installed to obtain the annual savings. However, it must be emphasized that there annual savings are tied up capital. The recourses are utilized more efficiently when implementing Scenario 1. Thus, the recourses can be used in other parts of the warehouse.

No larger initial investment has to be made. There is a plastic wrapper that needs to be moved and could be the reason for why the scenario has not yet been implemented. If the trailer is loaded from the side by the forklifts, there is no need for an actual dock. Instead, the trailer canopy can be removed and the forklifts will load the trucks from ground level. The truck driver can assist to correct the position of the SKUs.

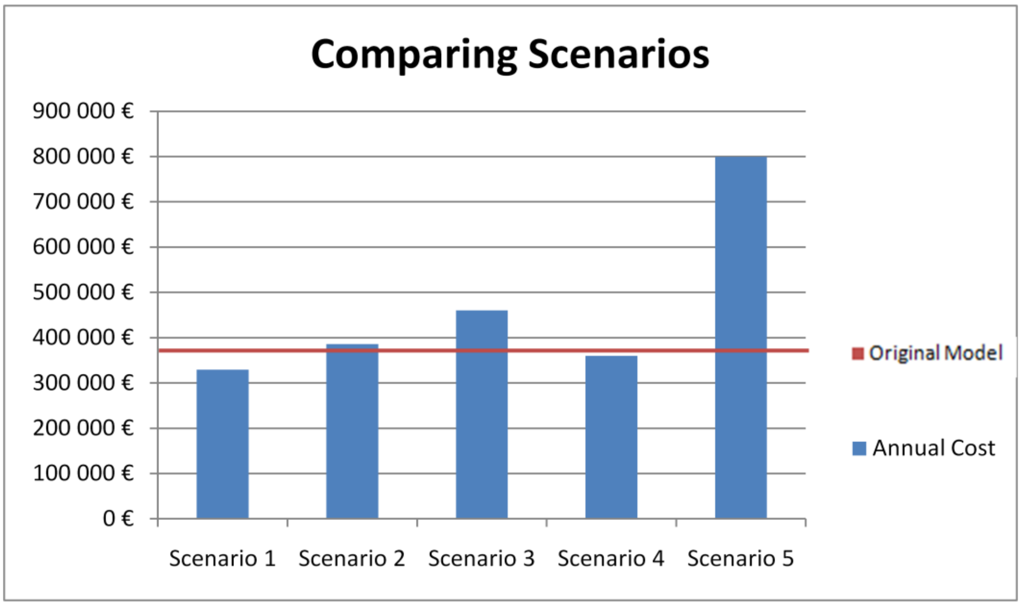


Figure 54: Annual Cost

7.2 Conclusion

In this thesis, a discrete-event simulation model have been developed in order to run experiments exploring how the FGI in Arganda can improve its performance and reduce the total cost. The findings indicate if the FGI in Arganda implements one extra loading dock, the annual savings are approximately 43000€. The result will have a positive effect on the life-cycle cost of the packaging material. The savings are mainly connected to a more efficient use of the forklifts. Therefore, the savings will contribute to having forklifts available which can assist other parts of the warehouse and factory. The findings confirm what the warehouse management team have been discussing, but has not investigated in detail.

For Company, the investigation has contributed to an improved understanding of how the customized orders are affecting the FGI. Through simulation, bottlenecks have been identified and knowledge of the complex parts, the behaviour of a FGI and its dynamics haves been obtained. The performance of the FGI has shown to be extremely sensitive to the sizes of the bins. In an ideal scenario, each production order would have a bin with a matching size. In the real system, this is not always possible due to lack of space. The goal should be to have a layout with additional small bin sizes and consider a rack to avoid mixing of orders. This would reduce the double handling and in a wider perspective, reduce the life-cycle cost for the packaging material.

This simulation model of the FGI is also a step towards a complete factory simulation which is a long term strategy for Company. The strategy involves having a factory simulation model for every packaging material factory by the end of 2017. The first goal is to have a factory simulation model of the Arganda factory by the end of 2012. To reach this goal, simulation models have to be developed for each activity of the factory. Once all models have been validated, the idea is to connect them into a complete factory simulation. By having a factory simulation, the complete flow can be analyzed. Furthermore, the production of tomorrow can be simulated to see for example how a rush order affects all parts of the factory and the associated costs. Thus, it will be a major asset for efficient planning of the shorter production orders. The development of simulation models of the different activities, will build a library of models. These can be used as a base for the future factory simulations. The model library, in combination with knowledge and experience gained, will reduce the development time for upcoming factory simulations. Thus, the advantages of the factory simulation will be obtained for each factory within the time limit for the long term strategy.

7.3 Further Research

If Company finds these results interesting, the recommendation would be to simulate the FGI for a longer time with more runs. Retrieving empirical historical data for the arrival SKUs is essential for a total validation of the simulation model. If this data is found and the model validated with this data, the credibility f the model will increase dramatically. The generated data from a simulation model that was retrieved for this study is not as reliable as empirical data. It is possible that the result from the empirical data might give a more exact result and predict more how the system will behave over a longer period. During a brainstorming, numerous scenarios were created. These could also be experimented with:

A. All forklifts are working in a single team

All forklift can either be picking or receiving pallets instead of being separated in picking team or receiving team.

B. Change the height constraint so it is possible to stack four full size pallet on top of each other

By doing this it will be possible to stack more SKUs in the warehouse and the capacity for the warehouse will increase. The result will be evaluated to see if there are any benefits to gain. The benefits should be compared against the disadvantages that probably will be longer put-away and picking time as well as investment in new forklifts.

C. Have dedicated storage for the most frequent orders.

By having the most frequent orders closest to the shipping zone it will probably go faster to deliver an order in case of emergency. This will be evaluated to see if there are any benefits to obtain.

D. Automated Storage & Retrieval System (AS/RS)

The purpose of the experiment is to see if an AS/RS system would be an effective solution and if the investment can be justified by the saving that comes from this new system.

E. Compare to a different type of picking policy

The current picking policy is not very efficient. By changing this, it will probably be more efficient and could have an impact on the travelling time in the FGI. The model gives the opportunity to see how this change will affect the system.

F. Implement a pre-staging area

The non-VMI customers have to send in a delivery order in advance to notify Company when they will collect the ordered SKUs. The ordered SKUs could be picked one day in advance and be placed in a pre-staging area. Once the truck has arrived, the picking forklift driver has all the SKUs collected in the pre-staging area close to the loading bay area.

G. Conveyor belt between Finishing Area and FGI

By installing a conveyor belt between the Finishing Area and the FGI, there will not be any need for the AGVs anymore. A conveyor belt does not have to be charged and has a higher reliability than a AGV. In addition, the conveyor belt can act as a buffer which stores more SKUs than the total amount that the AGVs can store. Finally, the forklift drivers can access any SKU on the conveyor belt much easier compared to unload a SKU from an AGV.

7.4 Reflections

It has been a real journey for us to work with this thesis. We have gained so much knowledge both within and outside the scope. It has been really fun and we have met a lot of new interesting people. All the hard work that we have put in to this project has paid off in form of competence and friends.

The outcome from this thesis for us has been that we have gained the knowledge of how fundamental the accuracy of the work is, which the simulation model is based on. If the pre-study is not done correctly or not defined enough, it will have negative consequences later in the study. We have also learned how to plan how to work in a big project, how to proceed with the work and to have faith in ourselves and believe in our decisions. We also gained the knowledge of a new software that we now feel that we manage. We are sure that all the knowledge gained from this thesis will be helpful in our future projects.

Company has been a great partner in this thesis. We think that the outcome for Company is that they now can see how the changing in the market demand and the new smaller orders will affect them in places that they probably did not know before. It is now possible to see how a small change can have such a big influence. The factory itself will be able to use this model to evaluate further scenarios in the direction of improving the performance even more. This study will visualize the problems and make it possible for Company to see that their strategy for the FGI might be in need of improvement. They are currently keeping stock for their customers when the customers should keep their own stocks. It would be more efficient for Company to have that way. However, there is a trade-off between being customer-friendly and cutting costs.

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Appendix I

Lund Warehouse

The warehouse in Lund does not only store finished goods. It also stores WIP as well as the aluminum foil used in the lamination process of the packaging material. The warehouse also stores additional material such as plastic polymers which are used in the ejection molding of the caps. The additional material is shipped together with the packaging material.

Layout

The warehouse in Lund has no physical boundaries between the FGI, WIP and Additional Material. The Finishing area is approximately 40% of the warehouse area (Olsson, 2012). The layout of the warehouse is visualized in Figure 55.

Figure 55: Layout Warehouse Lund

There are 148 bins with 3-7 pallet positions in each bin, with a vast majority of 7 pallet positions. This gives a total of 750 pallet positions. The standard SKU (1 litre packages) contains 5 reels on each pallet. Three SKUs are allowed to be stacked per pallet position. However, if the SKUs are smaller than the standard SKU, additional stacking number is allowed. The pre-staging area contains 20-30 bins depending on how many of the shared bins that are needed. The data regarding the material flow is presented in Table 38 (Olsson, 2012).

FGI Lund	
Average in stock	1700 pallets
Weekly turnover	1700 pallets
Throughput time	1 week

Table 38: Current status FGI Lund

Order

The minimum order size is 170 000 packages which corresponds to two standard sized SKUs (Figure 17). The average order size corresponds to approximately 6 SKUs which will occupy in total two pallet positions. Once the order is placed, a delivery order should be placed by the customer before seven days to ETD, to give the warehouse support time to plan the shipping activities. When a truck is loaded, the invoice is sent to Company International in Switzerland. Company International will then send the invoice the customer. The Throughput time is representing the time from arrival to the FGI until the ETD. The total lead time for the product is in average 15 days, starting from the order is received until ETD. Customers are allowed to store their orders up to 21 days after ETD in the FGI.

Receiving & Putaway

The SKUs arrive from the production with AGV. One team of four forklift drivers handles the receiving and put-away process, where the total workload is estimated to one forklift driver (Olsson, 2012). This team is also responsible for the WIP and aluminium foil flow in and out of the warehouse. The receiving team operates 24 hours per day, seven days per week.

Picking & Loading

The second team of 6 forklift drivers are responsible for the picking and shipping process. Once a picking list is received from the warehouse support, the forklift driver picks the ordered SKUs and places them in a pre-staging area. The pre-staging area acts as a buffer for the upcoming shipping the following day according to the delivery order. The complete order is placed either in a bin dedicated as a pre-staging bin, or in a shared bin which can be used for both storing and pre-staging. When the trucks arrive, the forklift driver receives a shipping list and places the SKUs in the loading bay area. From here, the trucks are loaded with smaller pallet trucks, see Figure 25. Domestic trucks are loaded by the truck driver and foreign trucks are loaded by the forklift drivers (Andersson, 2012). Two trucks can be loaded at the same time. The shipping activities are limited to 07.00-16.00, Monday to Friday.

Trucks & Containers

The trucks are usually of the *Euroliner* type (Figure 29) which can be loaded with 22 standard sized SKUs (Figure 17). The containers can either be 20 ft or 40 ft. If the 20 ft container is loaded, it can be loaded with either one or two layers of SKUs. If a 40 ft container is loaded, it can only be loaded with on layer of SKUs due to the maximum weight allowed (Olsson, 2012).

Warehouse Support

There are also 4 persons in the warehouse support. Their main responsibilities are to order trucks according to the delivery orders received from the customer and provide the forklift drivers with picking and shipping lists. The trucks are ordered from the Logistic Control Tower in Amsterdam, who orders trucks for all Company factories in Europe. A Warehouse Manager is responsible for all the warehouse activities.

Key Performance Indicators

The FGI in Lund is evaluated with the following KPIs:

- Perfect Delivery
    - Order delivered on time
    - Order delivered in full
- Inventory Level

The Perfect Delivery contains both order delivered on time and order delivered in full. *Order delivered on time* was until recently measured at the ETD, but is in progress to be measured in Actual Time of Arrival (ATA). This means that Company has to guarantee when the order is delivered to the customer. *Order delivered in full* has a ±5 % deviation from the actual order size to be considered *full*. The goal for this year Perfect Delivery is 54,6% (Andersson, 2012).

The Inventory Level is on average 1700 SKUs. A lower level means a lower accumulated holding cost, but also a higher risk of stock-outs. The average level of today is considered a good level to maintain the flow (Olsson, 2012).

Current Issues

A main issue when it comes to stacking is the lack of ability to stack a SKU, if the top reel in the lower SKU is too small. This means that one pallet position could be occupied by a single SKU if the top reel diameter is too small.

Another issue is the double handling of SKUs. Since the bins have a significantly larger capacity compared to the average order, there are mixed orders in some bins. Because of the use of a *First-In -Last-Out-principle* in the bins, blocking SKUs have to be moved to be able to reach SKUs according to the picking list. This procedure could be time consuming if there are many SKUs to replace. In addition, the pre-staging activity is also a double handling of the SKUs.

Misplaced SKUs is another issue that is considered time consuming. When the SKUs are picked to the pre-staging area, it happens that one SKU is missing. Each shift is spending approximately 30 min to look for misplaced SKUs (Haraldsson et al, 2012).

A fourth identified issue is the amount of time which is value added in the value chain. Only 0.32 days or in other words 98% of the time there is no value added to the product and half of this time it is stored in the FGI (Haraldsson et al, 2012). This indicates that there could be some major savings made as well as increased customer satisfaction if the Throughput time in the FGI is reduced.

SKU Flow Chart Lund

A detailed description of the SKU flow is presented below:

1. Pallet arrives to the finished goods area from the finishing area in the Finishing Area where the pallet is loaded, labelled and wrapped in plastic.
2. Pallet is received and scanned by a forklift driver. All necessary data is received from the scanning process. The WMS suggests a random available bin in the FGI.
3. Is it a rush order?
    - 3a. YES.
      The SKU is not scanned and are transported directly to the loading bay area.
    - 3b. NO.
      The SKU is picked up and scanned.
4. The forklift driver decides where to put the pallet: in the suggested bin, or in a bin chosen by the forklift driver.
5. The pallet is placed in the chosen bin.
6. Picking order is received.
7. Pallet is picked by a forklift driver.
8. Pallet is placed temporarily next to the bin since it is blocking other pallets that are to be picked and placed in the pre-staging area.
9. Pallet is placed in the pre-staging area.
10. Shipping list is received.
11. Pallet is picked and transported to the loading bay area.
12. Pallet is placed in the loading bay area.
13. Is the shipping associated with a container?
    a. YES
       One of the picking forklift drivers will do the loading of the container.
14. Pallet is picked by truck driver

END: Pallet is placed in the truck or container.

The SKU flow Chart is presented in Figure 56.

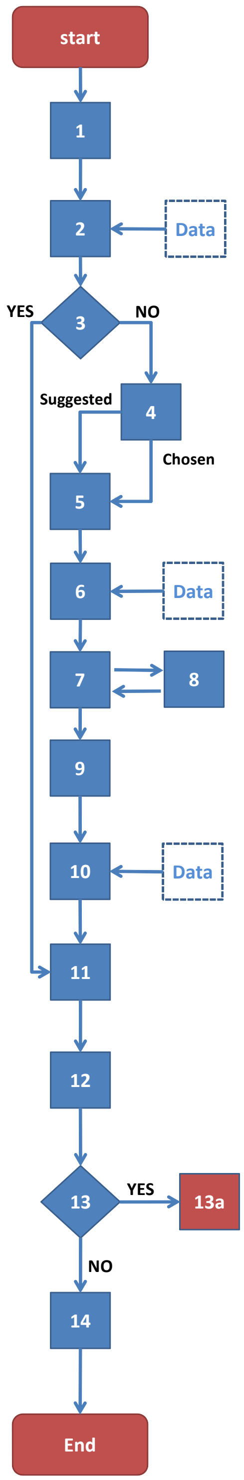

Figure 56:SKU Flow Chart Lund

Appendix II

Stakeholders

To visualize the finished goods flow between the different stakeholders, Figure 57 has been created. The SKU is received by the forklift driver after leaving the Production. The forklift driver put it in storage until it will be picked and loaded onto the forwarder's truck. It will either be transported directly to the customer or first stored in the external warehouse and then transported to the customer.

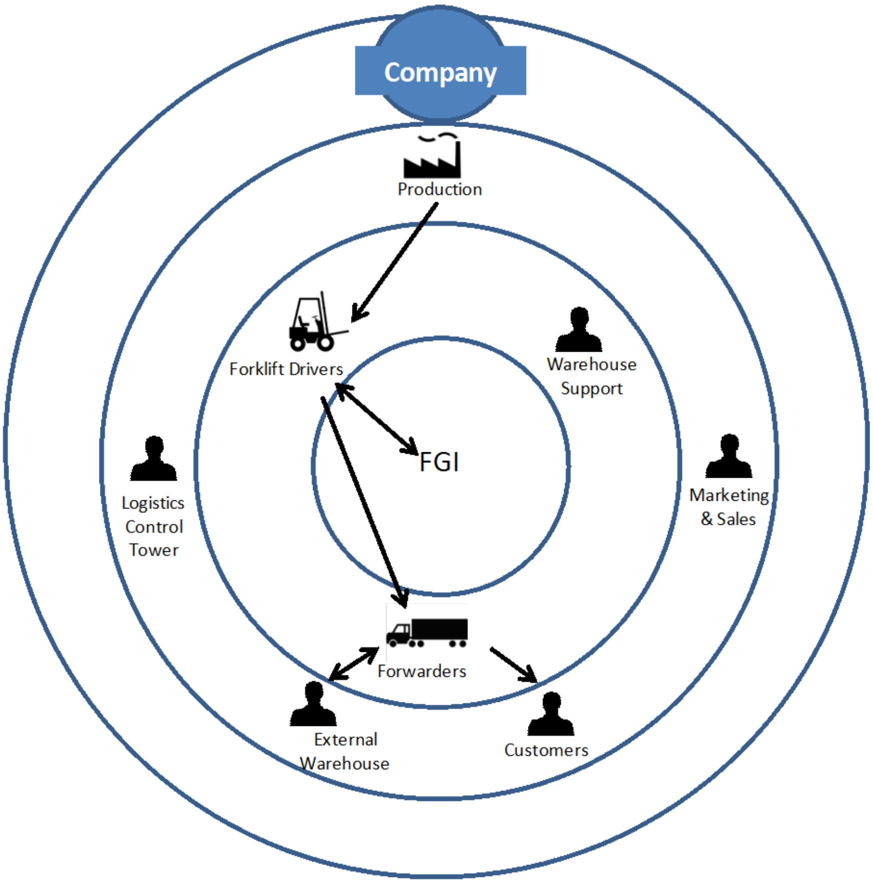

Figure 57:Material Flow Stakeholders

The information flow between the different stakeholders is visualized in Figure 58.

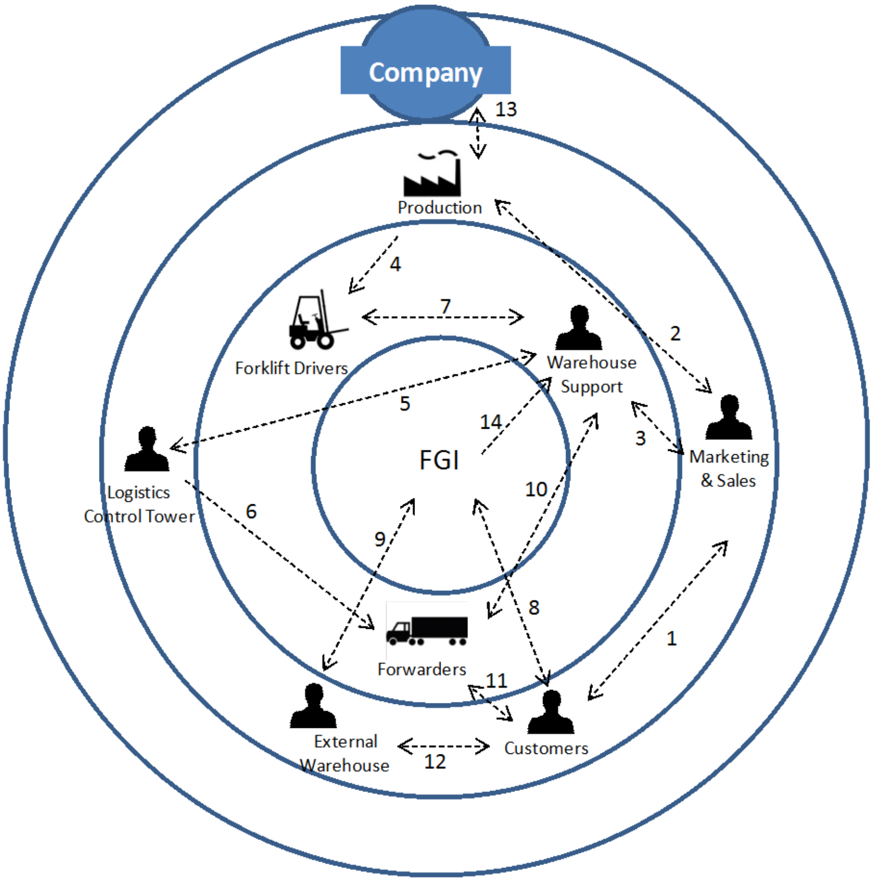

Figure 58:Information Flow Stakeholders

The information flow is very complex. The list below describes the identified information flow in detail:

1. Order is placed by the customer. Marketing & Sales provides an ETD. Customer places an delivery order
2. Marketing & Sales places the order in the internal production schedule where the Production Planner decides when it should be produced.
3. The delivery order is sent to the Warehouse Support. The Warehouse support confirms the ETD.
4. The forklift drivers scan the label and receive all data into the WMS-system regarding the SKU.

5. The Warehouse Support orders the trucks from the Logistics Control Tower needed to transport the order to the customer.
6. The Logistics Control Tower orders the needed trucks
7. Forklift drivers receives a picking list from the Warehouse support
8. Domestic customers have a VMI-system
9. The external warehouse shares stock information with the FGI and vice versa
10. The domestic truck drivers deliver picking lists to the Warehouse support. The International truck drivers receive shipping lists from the Warehouse Support.
11. The domestic customers deliver a picking list to the truck drivers. The International truck drivers delivers a shipping list and relevant documents to the customers
12. The domestic customers have a VMI-system which tells them what is in stock at the external warehouse.
13. Company International receives all information regarding the sales and costs from the factory in Arganda
14. Warehouse support receives information from the WMS-system regarding the inventory status

Requirements

Due to classified information, only an example of the identified needs and requirements can be seen in Table 39: Requirements. The model requirements are based on the system requirements. The model requirements are the system requirements translated in to the simulation model. The model is created so that the model requirements are fulfilled.

System Requirements	Model Requirements	Object being tested	Pass Criteria	Verification method	Result (Pass/Fail)	Comments	Follow-up actions	Result follow-up actions
The truck shall be loaded with a single layer of standard size SKUs if not said otherwise	the pallets shall not be stacked when loading	Truck (Queue)	no stacking when loading	Walkthrough	fail	sometimes the pallet are stacked	assumption in the model that no SKUs are stacked when loaded	pass

Table 39: Requirements

Appendix III

Arrival Data

The data for the arriving SKUs consists of the relevant information regarding each reel. One row is one reel and the “Reels per Pallet” label will decide how many reels there will be stacked on each pallet. The Production Order ID is a unique number for the quality and type of packaging material the customer has ordered. The “Amount of Pallets” label informs how many SKUs will be produced. An example of the input data for the generation of the SKUs can be seen in Table 40.

ArrivalTime	ReelID	ProductionOrderID	ReelDiam	ReelWidth	ReelsPerPallet	MaxReelsPerPallet	TransportType	PalletID	AmountofPallets
2011-01-03 10:19	675796/1/5	675796	1,1112	0,322	5	5	Road	1	22
2011-01-03 10:19	675796/1/3	675796	1,1112	0,322	5	5	Road	1	22
2011-01-03 10:19	675796/1/1	675796	1,1112	0,322	5	5	Road	1	22
2011-01-03 10:19	675796/1/4	675796	1,1112	0,322	5	5	Road	1	22
2011-01-03 10:19	675796/1/2	675796	1,1112	0,322	5	5	Road	1	22
2011-01-03 10:22	675785/1/5	675785	1,0896	0,305	5	5	Road	2	8
2011-01-03 10:22	675785/1/3	675785	1,0896	0,305	5	5	Road	2	8
2011-01-03 10:22	675785/1/1	675785	1,0896	0,305	5	5	Road	2	8
2011-01-03 10:22	675785/2/5	675785	1,0896	0,305	5	5	Road	2	8
2011-01-03 10:22	675785/2/3	675785	1,0896	0,305	5	5	Road	2	8
2011-01-03 10:24	675796/2/5	675796	1,1112	0,322	5	5	Road	3	22
2011-01-03 10:24	675796/2/3	675796	1,1112	0,322	5	5	Road	3	22
2011-01-03 10:24	675796/2/1	675796	1,1112	0,322	5	5	Road	3	22
2011-01-03 10:24	675796/2/4	675796	1,1112	0,322	5	5	Road	3	22
2011-01-03 10:24	675796/2/2	675796	1,1112	0,322	5	5	Road	3	22
2011-01-03 10:29	675784/1/4	675784	1,0896	0,305	5	5	Road	4	6
2011-01-03 10:29	675784/1/2	675784	1,0896	0,305	5	5	Road	4	6
2011-01-03 10:29	675784/2/4	675784	1,0896	0,305	5	5	Road	4	6
2011-01-03 10:29	675784/2/2	675784	1,0896	0,305	5	5	Road	4	6
2011-01-03 10:29	675784/3/4	675784	1,0896	0,305	5	5	Road	4	6

Table 40: Arrival data

Departure Data

The departure data is based on historical raw data from 2011. The picking orders have been sorted to match the generated arriving SKUs hence no SKUs can be picked which will not arrive to the FGI. For example, in the beginning of 2011, SKUs which have been produced in 2010 can be picked. However, the generated data only consists of SKUs produced in 2011. An example of the shipping lists used in the model can be seen in Table 41 (Manglanos, 2012).

Picking Date	Picking Nº	ProductionOrderID	AmountofPallets
2011-01-04 09:31	202439189	675628	4
2011-01-04 13:27	202439064	675796	22
2011-01-04 14:03	202439865	675202	10
2011-01-04 14:03	202439865	675881	9
2011-01-04 14:03	202439865	675201	3
2011-01-04 15:04	202440558	675882	5
2011-01-04 15:04	202440558	675164	13
2011-01-04 15:04	202440558	675877	4
2011-01-04 15:12	202440575	675877	9
2011-01-04 15:12	202440575	675878	13
2011-01-04 15:36	202440625	675872	13
2011-01-04 16:11	202440288	675631	7
2011-01-04 16:33	202440437	675736	8

Table 41: Departure Data for Picking Lists

Appendix IV

All throughput and inventory level data from the results from the scenario runs will be presented below. In addition, calculations will be presented for the original model and optimum bin size in Scenario: 6 deep bins.

Original Model: 6 Runs

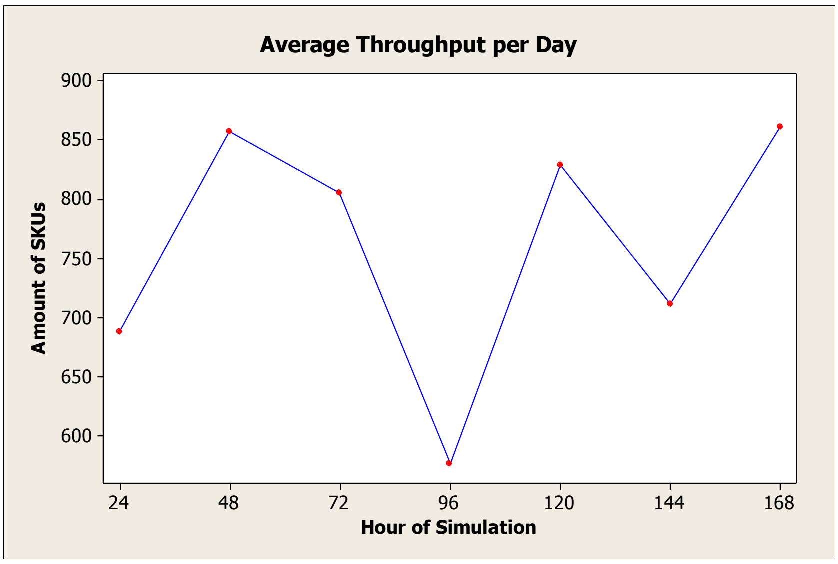

Figure 59: Average throughput original model

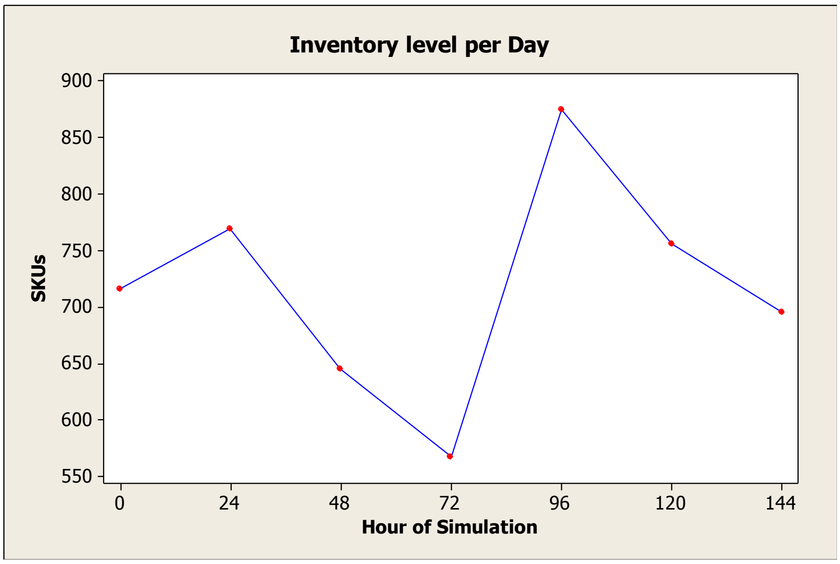

Figure 60: Inventory level original model

Original Layout	Through-put day 1 (95%)	Through-put day 2 (95%)	Through-put day 3 (95%)	Through-put day 4 (95%)	Through-put day 5 (95%)	Through-put day 6 (95%)	Through-put day 7 (95%)
mean	**688**	**858**	**806**	**577**	**829**	**712**	**862**
conf. Interval	634-742	817-900	743-869	556-598	800-859	656-768	844-881
Std dev	51	39	60	20	28	54	18
min	620	817	729	563	778	641	842
max	751	929	868	617	854	772	888
inventory level	**716**	**769**	**645**	**567**	**874**	**756**	**695**

Table 42: Result Performance Parameters original model

Calculated Cost

The costs have been calculated in the following way:

Total Handling cost=15.7 €/ SKU

The Picking Cost represents 50 % of the Total Handling Cost =>

Relocation cost = 25% of total handling cost = 15.7/4 = **3.93€/ SKU**

Relocation Cost for 7 days=3.93*Number of Relocations=3,93*658=**2586**€

Average Relocation Cost per day=2586/7=**369€/day**

Annual relocation cost= 50 weeks*5 days*369=**92250€**

Travelling cost=55% of Picking Cost=0,55*0,5*Total Handling Cost=0,55*0,5*15,7=**4,3175€/SKU**

Avg. Travel distance per SKU= $\frac{Total\ travel\ distance}{Total\ throughput+Number\ of\ relocations}=\frac{825585}{5333+658}$=**137,8 m**

Travel Cost per meter= $\frac{\text{Avg.Travel distance per SKU}}{\text{Total throughput}*\text{Travelling Cost}}=\frac{137{,}8}{5333*4{,}3175}$=**0,006 €**

Total Travel Cost for 7 days= Travel Cost per meter*Total Travel Distance=0,006*825585=**4940 €**

Average Travelling Cost per day= 4940/7**= 706€**

Annual Travelling Cost= 50weeks*5days a week*706€= **176461 €**

Holding Cost=0.9 €/SKU and day

Holding cost = Average inventory level *(stay time/one day) *0.9=**413€/day**

Annual Holding Cost = 50weeks*5days a week*413=**103250€**

Extreme Condition Test

Extreme Conditions	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
mean	**145**	**7,1**	**16567**	**5323**	**1052473**	**5211**
Confidence		5,1-9,1	12002-21133	5304-5343	1031444-1073502	
Std dev		2,8	6383	27	20035	0
min		2	12540	5270	1029654	5211
max		12	28568	5363	1083639	5211
N=6						

Table 43: Result Extreme Condition Test

Scenario1: Four trucks three forklifts. 6 Runs

4 trucks and 3 forklifts	Average inventory level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
Mean	**628**	**451**	**36511**	**5234**	**861494**	**5211**
Confidence		332-569	35360-37392	5192-5277	851174-871814	0
Std dev		113	839	40	9832	0
min		278	35021	5161	848828	5211
max		575	37229	5271	870528	5211
N=6						

Table 44: Performance Parameters Scenario 1

4 trucks, 3 forklifts	Through-put day 1 (95%)	Through-put day 2 (95%)	Through-put day 3 (95%)	Through-put day 4 (95%)	Through-put day 5 (95%)	Through-put day 6 (95%)	Through-put day 7 (95%)
mean	**777**	**741**	**692**	**568**	**939**	**714**	**803**
conf. Interval	754-800	716-766	672-712	565-572	924-954	689-739	784-821
Std dev	22	24	19	3	15	24	17
min	747	720	661	563	913	685	774
max	809	785	717	572	956	742	823
inventory level	**582**	**546**	**539**	**575**	**891**	**663**	**600**

Table 45: daily throughput scenario 1

Scenario 2: Six Deep Bin. 6 Runs

6 Deep Lanes	Average inventory level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
Mean	**686**	**771**	**49572**	**5375**	**868766**	**5211**
Confidence		671 - 870	48210 - 50934	5339 - 5410	858069-879464	0
Std dev		121	1656	44	10192	0
min		663	47482	5308	853073	5211
max		985	52394	5425	881656	5211
N=6						

Table 46: Performance parameters Scenario 2

6 Deep Bins	Through-put day 1 (95%)	Through-put day 2 (95%)	Through-put day 3 (95%)	Through-put day 4 (95%)	Through-put day 5 (95%)	Through-put day 6 (95%)	Through-put day 7 (95%)
mean	**729**	**872**	**757**	**565**	**899**	**734**	**819**
conf. Interval	666 - 792	804 - 940	705 - 810	554 - 575	867 - 930	700 - 767	802 - 836
Std dev	76	83	64	13	38	41	21
min	620	765	680	542	825	680	785
max	808	987	826	577	928	802	839
inventory level	**720**	**732**	**594**	**565**	**884**	**696**	**613**

Table 47: daily throughput scenario 2

Calculating optimum bin size

K= the depth of the bins
q_i=order quantity
z_i= stack height in number of SKUs
n= number SKU´s
a= aisle width

Table 48: variables optimum bin size

$$k=\sqrt{\frac{a*1*\sum_{i=1}^{n}\frac{q_i}{z_i}}{2*n}}$$

a=12 m

z=3 m

q= average 15 SKUs/order

n=538 different type of SKUs => k=6 pallet position deep

Scenario3: Vertical Rack

Vertical rack	Average inventory level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
Mean	**797**	**1184**	**60578**	**5310**	**841905**	**5211**
Confidence		766-1602	57405-63752	5167-5452	806590-877220	0
Std dev		398	3024	136	33646	0
min		751	57506	5084	800508	5211
max		1601	65318	5473	874005	5211
N=6						

Table 49: Performance Parameters Scenario 3

Vertical Rack	**Through-put day 1 (95%)**	**Through-put day 2 (95%)**	**Through-put day 3 (95%)**	**Through-put day 4 (95%)**	**Through-put day 5 (95%)**	**Through-put day 6 (95%)**	**Through-put day 7 (95%)**
mean	**632**	**780**	**801**	**689**	**792**	**763**	**844**
conf. Interval	583-681	701-860	771-831	609-786	740-843	692-834	803-885
Std dev	47	76	29	84	49	68	39
min	587	670	754	537	729	664	799
max	710	880	833	772	858	856	885
inventory level	**734**	**843**	**797**	**724**	**919**	**838**	**726**

Table 50: daily throughput scenario 3

Scenario 4: 4 truck 4 forklifts

4 trucks and 4 forklifts	Average inventory level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
Mean	**627**	**414**	**36968**	**5224**	**856771**	**5211**
Confidence		363-465	35630-38630	5197-5290	847187-866354	0
Std dev		49	1275	44	9130	0
min		348	35445	5186	846980	5211
max		486	38849	5318	869219	5211
N=6						

Table 51: Performance Parameters Scenario 4

4 trucks, 4 forklifts	Through-put day 1 (95%)	Through-put day 2 (95%)	Through-put day 3 (95%)	Through-put day 4 (95%)	Through-put day 5 (95%)	Through-put day 6 (95%)	Through-put day 7 (95%)
mean	**776**	**744**	**690**	**564**	**941**	**714**	**814**
conf. Interval	711-842	704-784	678-702	554-576	927-954	686-743	796-832
Std dev	62	38	12	10	48	27	17
min	669	721	670	554	834	664	797
max	850	820	705	582	973	740	846
inventory level	**580**	**545**	**535**	**573**	**893**	**663**	**600**

Table 52: Daily Throughput Scenario 4

Scenario 5: Higher Capacity Layout

High capacity layout	Average Inventory Level	Number of relocations (95%)	Average stay time in racks (95%) (s)	Through-put Total (95%)	Forklift average total distance (95%) (m)	Input (SKU)
Mean	**786**	**1311**	**56221**	**5220**	**1435681**	**5211**
Confidence		674-1948	52804-59639	5016-5423	1416742-1454619	0
Std dev		607	3256	194	18043	0
min		732	52424	4951	1410485	5211
max		2071	60257	5456	1466361	5211
N=6						

Table 53: Performance Parameters Scenario 5

High capacity layout	Through-put day 1 (95%)	Through-put day 2 (95%)	Through-put day 3 (95%)	Through-put day 4 (95%)	Through-put day 5 (95%)	Through-put day 6 (95%)	Through-put day 7 (95%)
mean	**622**	**855**	**815**	**626**	**728**	**741**	**833**
conf. Interval	541-703	812-898	749-880	536-717	604-852	703-779	784-881
Std dev	77	41	62	86	119	36	46
min	490	805	752	561	578	703	779
max	723	915	879	772	858	797	884
inventory level	**727**	**846**	**725**	**638**	**896**	**879**	**789**

Table 54: Daily throughput scenario 5