TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

OPTIMISATION OF SUB-ASSEMBLY PROCESS IN RADIO MANUFACTURING

RAADIOTOOTMISE ALAMKOOSTU PROTSESSI OPTIMEERIMINE

MASTER THESIS

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Tallinn 2020

(*On the reverse side of title page*)

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Thesis main objectives:

1. Analyse the sub-assembly process flow in classic radio production
2. Identify the bottlenecks and efficiency problems
3. Propose improvements

Thesis tasks and time schedule:

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3.	Simulating and analysing the process	April 3
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PREFACE

The thesis was initiated by Annemari Sepp, who works in Ericsson Eesti AS as a project manager. Due to the ongoing changes in production processes and new automated processes replacing the old ones, the supporting processes need to be analysed in the new environment. The initiative for the improvements started already 18 months ago and now is the convenient time to analyse the sub-assembly process of radio production.

I would like to thank Vjatseslav Koop who is working in Ericsson Eesti AS as an improvement manager who helped with his wide knowledge of the processes inside the company and all the other colleagues who have supported me throughout the process.

Keywords: Process optimisation, automated transportation, discrete event simulation

List of abbreviations and symbols

AGV – Automated Guided Vehicle

AI – Artificial Intelligence

AMR – Autonomous Mobile Robot

DES – Discrete Event Simulation

ESD – Electrostatic Discharge

IoT – Internet of Things

MES – Manufacturing Execution System

MiR – Mobile industrial robots

NPI – New Product Introduction

PBA – Printed Board Assembly

PC – Personal Computer

PLC – Programmable Logic Controller

RFID - Radio-Frequency Identification

ROI – Return on Investment

SMA – Surface Mount Assembly

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INTRODUCTION

Ericsson is one of the leading information and communication technology service providers in the World. With constant development of new products and increasingly rapid pace of introducing products to the market, new ways of manufacturing need to be developed. The mentality of implementing new ways of working is well established in the Ericsson Supply Site Tallinn – one of the four Ericsson owned manufacturing sites. With the growing number of new product introductions and project-based production, the mass production of the factory must be improved and automated to shift the focus of manual production towards new products.

Due to changes in mass manufacturing and the implementation of automation, the factory will introduce two automated processes into the main flow of production – automated main assembly and automated packing line. These are only some of the automation activities going on in the factory; however, with these changes, the support processes such as material replenishment, sub-assembly process and internal transportation will be impacted. The need for changes in the supporting processes is the basis of this thesis and more specifically, the sub-assembly process and its associated internal transportation, will be the focus. The main goal of the thesis is to optimize the sub-assembly process of radio production in accordance with all the changes happening thanks to automation.

In the first two parts of the thesis, an overview of the company and the whole production including the current sub-assembly process is given. This part will include the basis of the analysis by setting the requirements, identifying the wastes, and choosing KPIs to compare the possible improvements. In the third part, the analysis method for the current sub-assembly process flow is chosen an evaluation of simulation programs is made, and process simulations are performed and optimised in Tecnomatix. From these results, the bottlenecks, efficiency issues, and other problems are gathered. In the fourth part the new flow will be analysed with proposed changes. The improvements will be made step-by-step while considering different possible scenarios. The changes will be introduced into the simulation and the new statistical data will be analysed. Based on this data improvements will be proposed.

Additional to the directly simulated changes, future possible improvements for further consideration are offered and an implementation plan with several increments is created to enable the changes to be done in the in an effective manner. Finally, an economic feasibility study is conducted to ensure the cost efficiency of the improvements.

1 OVERVIEW OF ERICSSON SUPPLY SITE TALLINN

Ericsson was founded in 1876 and has since then risen to be the leading Information and Communication Technology (ICT) provider to mobile service providers. The headquarters of the company is in Stockholm, Sweden and the total number of employees is close to 100 000. Ericsson has 4 manufacturing sites: Estonia, China, the U.S., and Brazil. [1]

Ericsson Supply Site Tallinn (ESST) was established in 2009 and has been developing from a mass-manufacturing factory towards a high mix-low volume manufacturing site. Today there are around 2100 employees from almost 50 different nationalities working in two factories and one office in Tallinn.

Ericsson is constantly improving the ways of working and to provide better products for the customers. The company has been certified with many international standards including certifications from the following two ISO families: the ISO 9001 for quality management systems and ISO 14001 for environmental management.

1.1 Portfolio of Ericsson products

Ericsson is operating in 4 different business portfolios: networks, digital services, managed services, and IoT and new business.

Networks portfolio

The networks portfolio is focused on offering solutions to service providers. The network technology consists of hardware, software, and related services and spans across radio, core and transport networks. The solutions offered by Ericsson enable end-to-end 5G deployment while supporting the current 4G business to still take the full advantage of the existing infrastructure.

The main part of the networks is the Ericsson Radio System which includes different products that all work in a common system. An overview of the different products can be seen on Figure 1.1.

Figure 1.1 Ericsson Radio System [2]

Digital services

The digital services portfolio is focused on modernizing, digitalizing and shaping new business models for Telco operators. This is done through innovative customer engagement platforms, automated operations and programmable networks. The range of products in the digital services portfolio ranges from automated network operation and transforming business to cloud communication and infrastructure. The main aim of this portfolio is to support businesses in evolving and scaling in the digital era.

Managed services

The managed services portfolio is focused on simplifying the managed businesses and supporting the service providers in solving the complexity challenges that are coming along with 5G and IoT evolvement.

For that goal, Ericsson has developed a new AI-based Ericsson Operations Engine which consists of three main building blocks: service-centric business model based on business outcomes, end-to-end capabilities, and components to leverage data.

The product range in this portfolio covers all business-related services such as: smart design, data driven operations, intelligent optimization, seamless security, dynamic deployment.

Internet of Things (IoT)

The IoT portfolio is seeking additional profitable growth for the company outside of its core business. This is reached by building the technologies and skills in the growth areas and combining 5G and IoT to enable digitalization in several fields.

The focus of this portfolio is in IoT solutions to reduce the barriers to entry in fields such as: connected vehicles and smart manufacturing. [1]

1.2 Overview of production in Tallinn

The production in Tallinn is divided between two buildings where production is running 24/7 in two shifts.

The production can be categorised based on products into 5 distinguishable segments: classic radio, antenna integrated radio (AIR), RAN compute, Radio Site System, and printed board assembly (PBA). Next to the possibility to segment the production based on products, the production could be divided into mass production and prototyping.

The main emphasis of production in ESST is on new product introduction and industrialisation (NPI) as well as low volume production. There is smaller part of production dedicated for mass manufacturing (high volume production). It can be seen on Figure 1.2 that the production process types in ESST are covering almost all the types of production when visualised together, the classification used by Ericsson (in green) and classification in theory (in blue) [3]. Therefore, the technologies and processes used in the factory need to accommodate all three types.

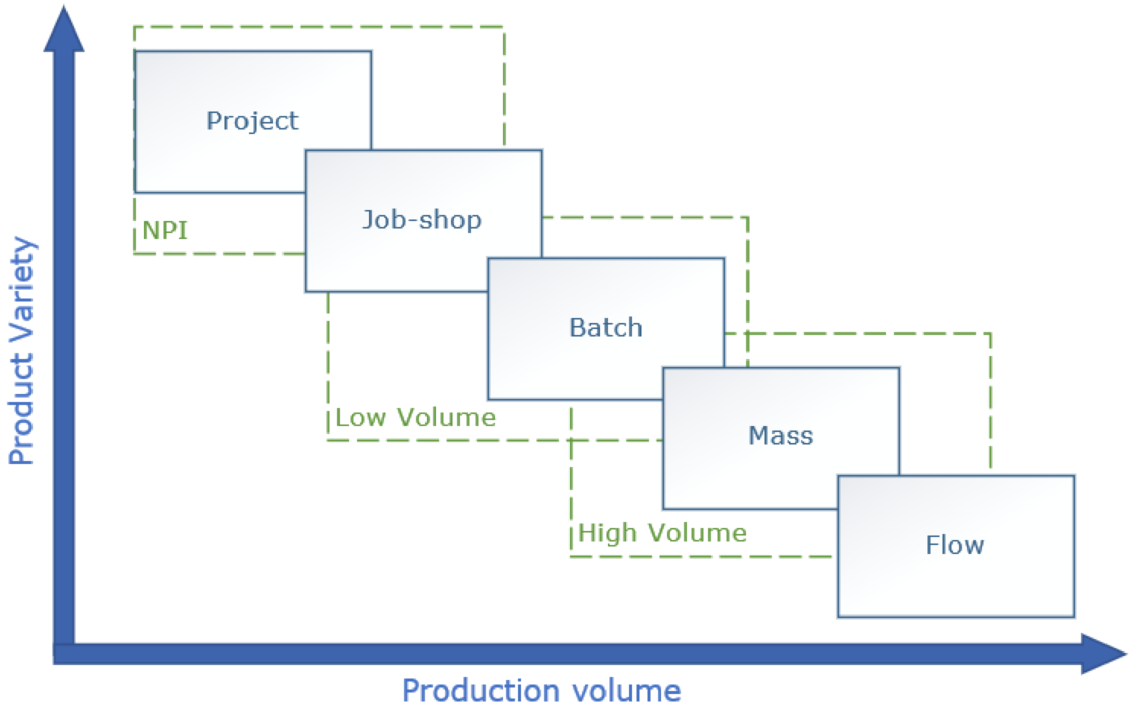

Figure 1.2 Types of production processes

For each of the segments, the products in them will go from prototyping towards mass production. As there are more products introduced than the capacity of mass production in Tallinn allows, some of the products will be outsourced from Tallinn for mass production.

The main engineering activities in Tallinn are design for manufacturing (DFM) and design for automated assembly (DFAA) from the product view. The engineers in Tallinn also develop production lines and processes based on product specifics. Building up the capability of the product to be mass produced ensures better outsourcing and better production efficiency.

1.3 New industrial systems in Ericsson

As can be seen from Ericsson's business portfolio, they are aiming towards overall digitalization and automation in various fields. While digitalization is mostly affecting the administrational side of the company, the automation is direct impacting the way Ericsson products are being produced around the world.

In the beginning of 2020 Ericsson opened its new factory in Texas. The factory in the U.S is the first Ericsson smart factory with the focus of production being on 5G products. The factory is fully automated and will enable smart manufacturing with the usage of industrial solutions such as automated warehousing solutions, automated assembly and packing, and automated transportation. [4]

Even though the site in U.S is the first to be built with full automation in mind, the activities are ongoing in all other sites towards automation. For example, all sites are using automated transport for internal logistics and the surface mount assembly (SMA) process is nearly fully automated.

The same progression towards automation can be tracked in the Ericsson Supply Site Tallinn as well. Some of the changes have already been implemented and some are still being developed. The factory has already deployed an automated process for SMA, automated dispensing, and in warehouse an automated storage and retrieval system is in place. The internal transport for SMA components is done with autonomous mobile robots (AMR) and the robots are being tested for main assembly materials transportation as well.

During the last few years the factory has been implementing new Manufacturing Execution System (MES) and test execution systems. [5] Last year, a new department of Smart Manufacturing was created for stronger support of several automated systems and constantly increasing need for smart machinery support. Furthermore, several smaller automation and new technology introduction projects are in development for reaching higher efficiency and better understanding of the state of processes.

The three biggest automation projects for the production process are automated main assembly, testing, and packing. With such big portions of the process being automated, a lot of other processes need to be changed. This also means new information infrastructures, new ways of material replenishment and new supporting mechanics. These changes require a lot of support processes to be changed as well and affect all the current manual production support processes. Amongst these changes it is a good chance to re-evaluate the current processes and make improvements where possible.

2 CLASSIC RADIO PRODUCTION PROCESS

In this paper, only the classic radio segment is focused on and it is considered that classic radio has two product families in production. The main flow processes for classic radio production are considered and most of the side processes such as repair and troubleshooting are not considered. Furthermore, the surface mount assembly (SMA) process is considered as a support process and will not be counted as part of the radio production.

2.1 Current classic radio segment production

The production of a radio is a 5-step process: sub-assembly, main assembly, testing, final assembly, and packing.

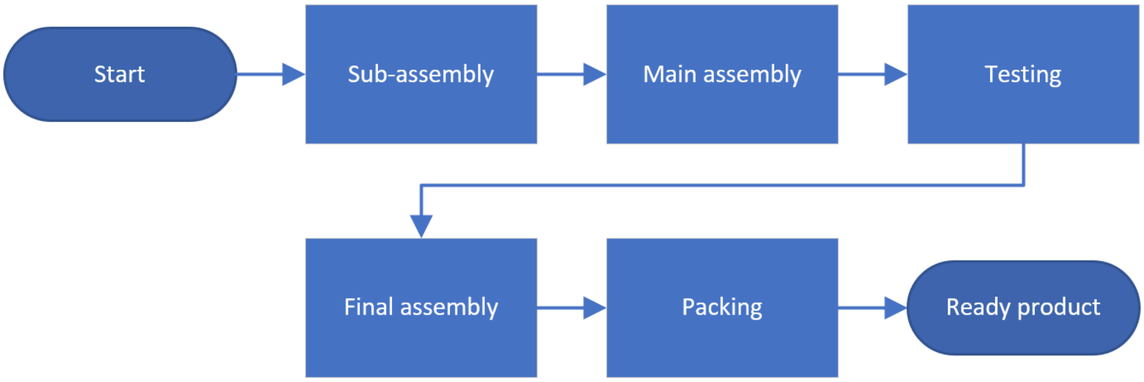

Figure 2.1 Classic radio production process

Sub-assembly

The sub-assembly process goal is to prepare the radio frame ready for the main assembly. For that the radio frame must be placed on the workpiece carrier, cleaned from dust, and a label with product serial number must be attached to the frame. The sub-assembly stations are located as the first workstation of each main assembly line.

Main assembly

The main assembly is done on an assembly line. Currently, the assembly is performed manually. The exact number of workstations on the line depends on the product specifics; however, each product goes through the line only once.

The main assembly consists of several tasks such as placement of components, dispensing, and screwdriving. The order and amount of these processes depends on the product and is deemed to not be important information for this paper.

Testing

The testing step is a functionality test of the assembled radio and the decision point whether the radio passes through to final assembly or not. To simplify the process, we can assume the testing for all classical radios is done in pool of testers (Testpool) and the input to Testpool is the same from all main assembly lines. The test is conducted with the radio on the workpiece carrier and the information about the radio is fetched from the RFID tag.

Final assembly

In final assembly the radio is being prepared to be sent to packing. The caps of connectors are assembled, and the radio goes through visual inspection for any scratches or damage that might have occurred during the previous assembly steps. The radios enter the final assembly on the workpiece carrier but are lifted from the workpiece carrier to be sent to packing. The workpiece carriers are then sorted and sent back to the sub-assembly area.

Packing

The packing is done manually with the help of different tools. The radios are packed either to single or multi-packs based on order and sent to the outbound warehouse for shipping.

2.2 Upcoming changes

As part of automation activities, some of the production flows will undergo changes. The main changes will be made in the assembly and packing processes which creates a need to re-evaluate the current sub-assembly process as well as the handling of workpiece carriers.

The upcoming automated processes retrieve all the product data from the RFID tag that is attached to the workpiece carrier. For this step, all the sub-assembly stations need to be updated and RFID writing capability needs to be added.

As the sub-assembly stations are at the beginning of each main assembly line, there must be a separate sub-assembly station added in front of the automated line as well according to the current set up.

As the RFID tag is attached to the workpiece carrier and the automated packing line will also need to fetch the product data from the tag, the radios need to arrive to the packing line together with the workpiece carrier. From there the workpiece carriers will be freed and sent back to the sub-assembly station. The packing line will be in the warehouse and therefore, the carrier needs to be replenished from there.

2.3 Sub-assembly process description

The sub-assembly process has several inputs and one output. To analyse the flow of the process correctly, it is needed to observe the input creation processes as well as the transportation and handling of these components. The main two input components for sub-assembly are the workpiece carrier and the radio frame, the outcome of the process is sub-assembly.

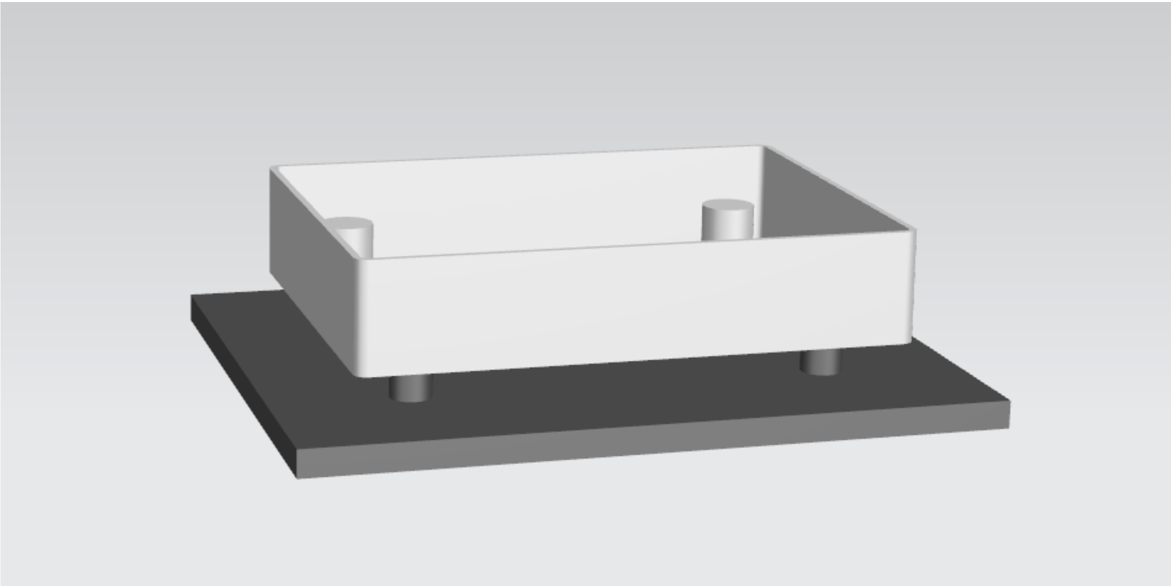

Figure 2.2 Sub-assembly of family A illustrative model (dimensions 400x500x130 (mm))

2.3.1 Workpiece carrier

Workpiece carrier is a re-useable carrier which has a RFID tag attached to it. The carriers are moving through the production flow together with one radio at a time and the carrier is freed currently after the final assembly and after the implementation of automated packing, the carrier is freed from there.

The workpiece carrier consists of 3 main parts: baseplate, RFID tag and towers. There are two different sizes for the baseplates for the two different product families and the tower configuration is based on the product that is meant to be transported with the carrier. In this paper the tower configuration is considered to be the same for all the products in one product family.

The two product families will be referred to as family A and family B. As the products in family B are bigger size than in family A, then the baseplate is also bigger for family B. It can be assumed that the measurements for family A baseplate are 400x500x20 (mm) and for family B 500x600x20 (mm). The baseplate is made from metal with a cut out in the middle for the RFID tag to be attached to a plastic cover.

The RFID tag used is an off-shelf product and has the coverage to enable writing and reading when the carrier is on the workstation.

The towers can be made from metal or plastic. For this paper it is considered only metal towers are used and the same towers are used for the families. It can be assumed the height of the towers when assembled to the baseplate is 70 mm and the diameter is 30 mm. Furthermore, it can be assumed the towers are screwed into the baseplate with a thread directly on the tower. As mentioned above then the tower placement on the baseplate can vary among different products; however, in this paper the configuration is deemed to be the same across the product family.

The weight of the carrier for family A is assumed to be 7 kg and for family B 10 kg.

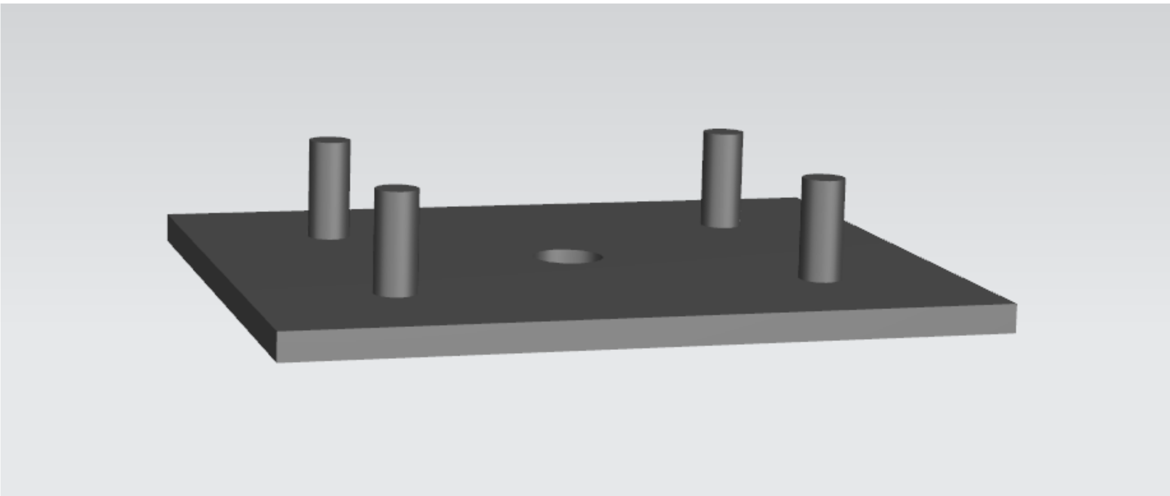

Figure 2.3 Carrier for family A illustrative model (dimensions: 400x500x20 (mm))

2.3.2 Radio frame

The radio frame is the first assembled component of the radio. The frame is made from metal and is covered with paint on the outer part. For mass production the frames are cast and then machined, for the prototype builds the frames can also be milled.

For this paper, the frame mechanics are simplified and all the cut outs, inner and outer shapes are ignored.

The frame product number and mechanics are specific for each product; however, it can be generalised that there are two types of frames in use: frame for family A and frame for family B.

For this paper the main parameters that are important to note are the measurements and the weight of the frames. The outer measurements of the frame for family A can be assumed to be 300x400x80 (mm) with the weight of 8 kg. For family B the measurements can be assumed as 400x500x90 (mm) and weight of 15 kg.

The frames are delivered to the factory in a multipack from the supplier. The number of frames in one box depends on the type of the frame and the suppliers own packing process.

2.3.3 Assembly process

The preparations for sub-assembly begin in the warehouse where the frames are kitted from the supplier package to trolleys from where the production workers can easily access the frames. The warehouse workers take action based on need as they are kitting the trolleys as soon as the empty material trolleys come back from production and the workers are not divided based on material; therefore, one worker can kit all materials for sub-assembly and main assembly as well as for other segments.

After the trolley has been filled, the full trolley is delivered to the buffer area where the full trolley is waiting for the signal from production for more materials. When the signal is received, the transportation worker delivers the trolley to the correct line in production. The transport workers are also a shared resource for all the material transportation, not dependent of the production segment.

In the sub-assembly workstation, the production operator is transporting the workpiece carriers from the end of the final assembly to the sub-assembly workstation where the warehouse transport worker has already delivered the frames. The layout of the workstation and its surroundings can be seen on Figure 2.4.

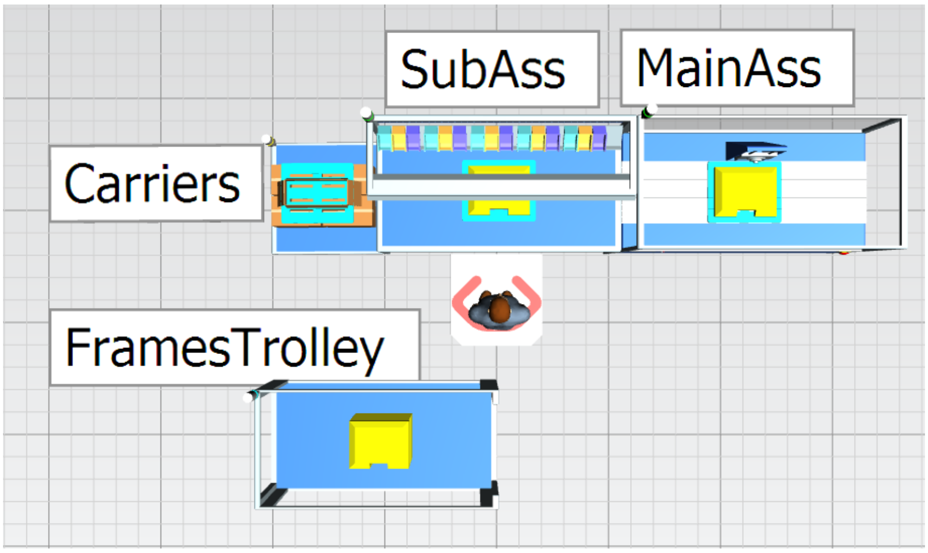

Figure 2.4 Sub-assembly workstation layout

The operator then pulls the carrier from the trolley to the workstation with the help of trolley lift and checks the carrier condition. The next step is to lift the frame onto the carrier with the help of a lifting tool. Then the frame is cleaned with a vacuum cleaner and after that the radio serial number label is attached to the frame. The label is then scanned, the information is registered in MES and is confirmed by the worker.

After the assembly is done it is moved to the next workstation. The operator is repeating the activities until the carrier trolley is empty and they will then replenish the carriers from final assembly to the workstation. The empty trolley is taken to the final assembly where it is switched for a full trolley.

When the frames on the material trolley are running low, the operator will send a signal through replenishment system to the warehouse to bring full trolley of materials and take the empty trolley back to the kitting area. For each workstation or material there is 2 trolleys circling between production and warehouse.

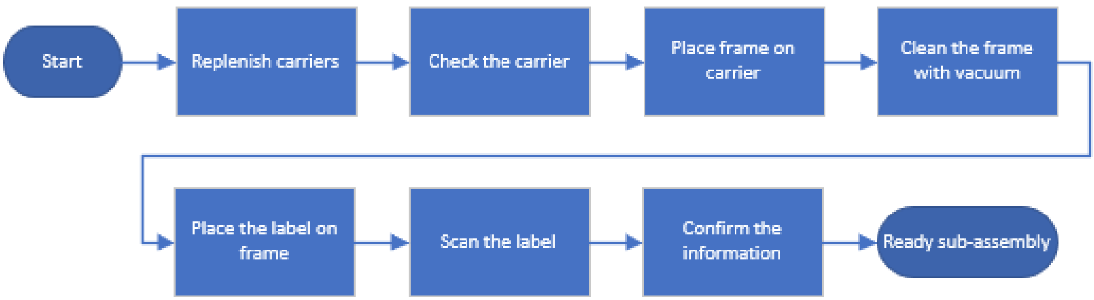

Figure 2.5 Sub assembly process

2.3.4 Resources used for sub-assembly process

The resources for sub-assembly consist of human and material resources. The material resources can be divided into one time and multi-usage resources.

The human resources needed for sub-assembly or enabling the sub-assembly process are warehouse workers: warehouse and transport worker; and production operators. The warehouse workers are all working commonly for all the production segments and are therefore, not connected to specific products or families. On the other hand, the production operators are working on a specific line and specific workstation and therefore, their useful time is related directly with the product cycle time.

The material resources that are used once are only the frames. The rest of the resources are used multiple times and are either circulating in the factory or are connected to the specific work-centre or activity.

In circulation there are the carriers that are circulating from sub-assembly, main assembly, testing, and finally from final assembly; and there are trolleys that either circulate between sub-assembly and final assembly or warehouse and sub-assembly. From stationary resources there is the worktable in the workstation that has an RFID reader/writer as well as computer to communicate to MES and run the software to enable RFID tag writing.

2.4 Waste identification

The lean methodology was developed in Japan, by the management of Toyota based on the learnings of Henry Ford's previous trials. The three fundamentals of lean transformation are philosophy, process, and people. [6] The main goal, therefore, should be better purpose, better processes and better people. This can be achieved through eliminating the waste.

Toyota identified seven plus one different waste categories that can help to identify the wastes in the company and eliminate them correspondingly. All waste is related to non-value adding activities and should be removed to increase efficiency. The wastes are described below.

1. Transportation. Movement of the materials, sub-products, products, etc in process or between processes. It also includes the movement of goods in and out of storage.

2. Inventory. Inventory is all the materials, sub-products, products, etc that are not used actively in processes. Excess inventory causes high costs for storage, longer lead times, more transportation and possible damaging of the goods.

3. Movement. Every motion performed by employee that is not creating value is considered as waste. Unnecessary movements include reaching and looking for parts, looking for tools and walking unless it is a value adding process.

4. Waiting. When workers are not working and are waiting for the process to finish, watch over automated process, wait for material or tools, or are not able to work due to lack of materials, process delays or bottlenecks, then this is considered as waste.

5. Overproduction. Producing more or earlier than needed by the customer creates other waste, such as excess inventory and transportation.

6. Over processing. When the products are processed with more steps than needed for example due to poor tool or design, then excess motion and work is generated. On the other hand, over processing can also mean providing better quality than needed and that is still considered as waste.

7. Defects. Producing defective parts causes adding work such as repair, rework, scrap, troubleshooting, which is non-value adding and should be avoided.

8. Skills. Using the workers for non-value-adding tasks when there is higher potential for the worker to create value, is considered as waste. [6]

2.5 Key Performance Indicators overview

It is important to measure the current state of the company or part of it to find the weaknesses and better the situation. These kinds of measurements can be done only by the company itself with relevant data analysis and defining its goals. There are different types of frameworks to support the goal setting and enabling to follow the success rate towards the goals.

For evaluating the success of an existing activity or process, the most common framework is to use key performance indicators (KPI). It should be noted that KPIs are static measuring framework where the current state is noted and then evaluated whether it is better or worse from the projected desirable outcome. [7] That is the main reason why they are so widely used in manufacturing companies as there is a lot of static data available and manufacturing processes are mostly rather stable in their performance. KPIs are an easy way to figure out where performance can be improved and after improvement the KPI goals need to be re-evaluated to fit with the new levels.

KPIs in Ericsson are used for each department to analyse the current state of performance. For this paper there are in total three KPIs that are relevant and will be counted as the basis for improvement.

Working time efficiency – the main aim of this indicator is to measure the efficiency of the employees on the factory floor. The goal is to increase the productivity of each employee and their utilisation. The KPI is measured monthly and the data is gathered per shifts. To calculate the actual input for the KPI the following equation is used:

$$Employee\ utilisation = \frac{Actual\ employee\ worktime}{Total\ available\ worktime}\ x\ 100\% \qquad (1.1)$$

Production cost – The cost of production for the whole KPI value is a complex equation combining all different parts of production where the cost is coming from; however, one of the variables is the amount of people which can be measured for the sub-assembly process and that can be improved based on the previous KPI. Furthermore, it can be assumed, that the production cost will be lower overall when the maximum output is reached with the shortest working time.

Automation level of inhouse transportation – This KPI is measured across the factory, considering all different transportation routes. For this paper the scope of the KPI is only the sub-assembly process and therefore, is only measured for this one process. It can be expected that any improvement in any of the separate processes impacts the overall factory's KPI positively.

3 CURRENT SUB-ASSEMBLY FLOW ANALYSIS

Industrial process simulation has several possible models; however, the most used model is the discrete event simulation (DES). In DES each event is followed by another and each of them have a logical transition to the next one. Using discrete events allows the simulation to gather a set of random events and connect them together while analysing the usage of resources and keeping track of the entities.

DES is widely used for material flow simulations, especially for designing and optimizing manufacturing system. [8] Examples of using DES for process simulation come from several fields such as healthcare, automotive industry, and supply chain [9] [10] [11].

The advantage of DES is the possibility to simulate several scenarios and configurations without investing time and money in real world trials. When the system is complex and not all the analytical data is known, then using DES helps to simulate the material flows in various ways. This makes short-term decision-making process quicker and more fact-based. [12] While running the discrete event simulation, the clock will not run in real-time but is started again at the beginning of each event. This allows the simulation to be analysed later based on events as the simulation can be ran with different behaviour due to usage of pseudorandom variables. Each trial has its own statistical result and by the end of the simulation a statistical result can be achieved. [13]

The results are then analysed based on lean methodology to increase efficiency by identifying what types of waste occur in the process and investigating how to eliminate them. Furthermore, the relevant KPIs will be measured.

3.1 Choice of the simulation software

The choice of software that can be used for DES is wide and they all have advantages and disadvantages. For this paper the choice will be made between 3 software programs. The three programs were chosen based on their use in industry and popularity: Visual Components [14], Arena Simulation [15], and Tecnomatix Plant Simulator [16].

Criteria for the choice are the following: ease of use, technical capabilities, and the authors personal preference based on their previous experience and knowledge.

Ease of use mark will be taken as average of the following criteria: requirement for training – the less training is expected, the better; resources for learning – the more resources are available the better based on Internet search; frequency of programming

– how much programming is needed to be done for a complex model, the less the better; and building time – how much time it takes to complete a complex model from the start, the shorter the time, the better. The technical capabilities mark will be an average of the following three: graphics – does the software support 3D models and the models graphical complexity; statistical reporting – how detailed the statistical report can be received from the program; and customization – how much can the models parameters be customized and own data be presented.

All the marks will be given based on authors own previous usage of the programs and therefore, should be considered as subjective. The program will be chosen only based on evaluations and not on measurable numbers such as cost and reaction time due to the changing nature of these values as the offers vary between companies and there is no public price for licencing these software programs.

The three programs will be evaluated, and the matrix can be seen in table 3.1. The points were given with the system where 1 was the highest mark and 3 the lowest. All the programs were evaluated relative to each-other. The final mark consists thereof the sum of the marks for each criterion – for ease of use and technical capabilities it will be average of sub-criteria. The program with lowest mark will be chosen for the simulation.

Table 3.1 Selection matrix for simulation programme

Criteria	Visual Components	Arena Simulation	Tecnomatix Plant Simulator
Ease of use (average)	3,0	1,5	1,5
Requirement for training	3	1	2
Resources for learning	3	2	1
Frequency of programming	3	2	1
Building time	3	1	2
Technical capabilities (average)	1,7	2,3	2,0
Graphics	1	3	2
Statistical reporting	3	1	2
Customization	1	3	2
Author's personal preference	3	2	1
SUM	**7,7**	**5,8**	**4,5**

The author’s personal preference score was given after testing out all three programs for the simulation requirements of this paper. The author tried making the as-is simulation on all three simulation software packages and tested which out of three would prove to have the most potential to provide the desired results of the simulation.

Firstly, Arena Simulation was tested and even though it was easy to make a linear process, adding two tracks that would be triggered by other processes state was impossible to achieve without knowledge of the specific coding needed. Learning about the code and logic behind it was complicated as there was not much information online about it. Next, Visual Components was tried and even though the logic in this program was much more understandable, the number of objects needed to create the simulation complicated the building process. Visual Components would be a good tool if a fully functioning digital twin would be needed to be built; however, for a temporary process simulation, the time and effort needed to be put in there is not worth the results.

Lastly, Tecnomatix Plant Simulator was used and even though it does need as much coding as Arena then finding resources online was much easier thanks to several forums that have active users discussing different simulation objectives. [17] Furthermore, for this software there was also a lot of books and learning materials available. The most help was received from the official Siemens Tecnomatix Plant Simulation Help [18] and Steffen Bangsow homepage [19].

From the selection Tecnomatix Plant Simulator will be the most suitable program for the author to conduct the flow analysis. The strongest capabilities that Tecnomatix has are the ease of use and frequency of programming. The program is user-friendly and gives a basic 3D model of the simulation as well as the 2D graphics. The author has used all three programs beforehand and feels themselves most comfortable in using Tecnomatix.

3.2 Data collection for the simulation

Process times

The data for the simulation was collected in two different methods: through observations and from the management systems where the time is logged. As it was not possible to observe all the processes, and at the same time, not all the process data was logged into systems, then the data will be used simultaneously and the longer timespan is used for the simulation in case both methods were possible to be used.

The data through observation was collected over the span of 30-minute observations using a stopwatch and then compared to the logged or theoretical data that is in the system. The theoretical data in system has been collected over a longer period in observation method by the engineers responsible for the process; however, this data will not be directly used in this paper and was only used to confirm the correctness of the observed data.

The data utilised in this paper is an approximation and is created solely for use in this paper. The data shall be referred to as SimData.

The SimData is shown in the table 3.2.

Table 3.2 SimData process times

Process step	**Time**	**Unit**
Kitting frame onto trolley per frame	30	s
Replenishment of carriers from final assembly (per 5 carriers)	180	s
Checking the carrier	5	s
Placing frame on carrier	30	s
Vacuuming the frame	10	s
Placing the label on the frame	10	s
Scan the label	10	s
Confirm the information	5	s

It can be calculated that the total time for sub-assembly is 70 seconds. Besides sub-assembly process times it is necessary to provide simulation times for main assembly as well to simulate the waiting time of sub-assembly as well. The SimData cycle times of main assembly are shown in table 3.3.

Table 3.3 Main assembly SimData cycle times

Product family	**Time**	**Unit**
Family A	300	s
Family B	360	s

Resources specifications

The resources used for the activities related to the sub-assembly that need specification are, availability of resources, working times, the specifics of trolleys used, and distances of transportation. Furthermore, it will be assumed that there are 4 production lines in total, 2 for each product family).

For this paper, it is assumed that all resources are available 100% of the time. This includes, the availability of carriers, frames, and workers. The useful working time of workers is assumed to be 8 hours per shift. The same working time calculation will be used for all production and warehouse workers.

Sub-assembly process preparation and process itself is using 2 types of trolleys – carrier and frame trolley. It can be assumed that the carrier trolley can fit 5 carriers and frame trolley can fit 9 frames at a time.

The distances of transportation are measured from the factory floor layout files and similar distances can be assumed to be true for this paper. The distances can be seen in Table 3.4.

Table 3.4 SimData distances for transportation

Start	End	Distance	Unit
Warehouse	Sub-assembly	150	m
Sub-assembly	Final assembly	100	m

3.3 As-Is simulation creation

The as-is sub-assembly simulation was made by taking into account what is required as the outcome of the simulation. For that reason, many of the processes were combined and others were focussed upon.

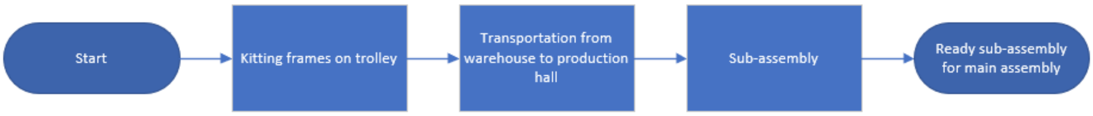

Figure 3.1 As-Is sub-assembly process

In the simulation, it was assumed that there are 4 production lines where 2 are producing family A products and 2 family B products. The lines were called A1, A2, B1, and B2 showing product family and the line number.

The simulation can be split into two parts: warehouse side and production side. The overview of the simulation can be seen on figure 3.1. The distance between the two sides is 150 metres as the assumed distance was said to be.

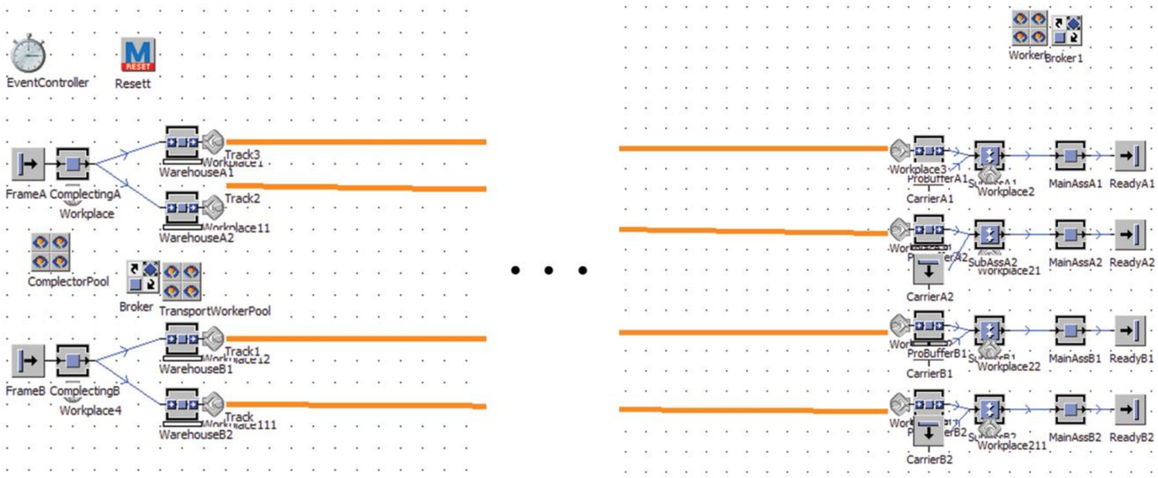

Figure 3.2 Top view of the 2D model

3.3.1 Warehouse side build

The warehouse part of the model consists roughly of 3 parts: source of frames, kitting frames on trolleys station (in Tecnomatix: complecting) and buffer. Next to them there are also two worker pools: ComplectorPool and TransportWorkerPool, together with a broker to enable worker allocation.

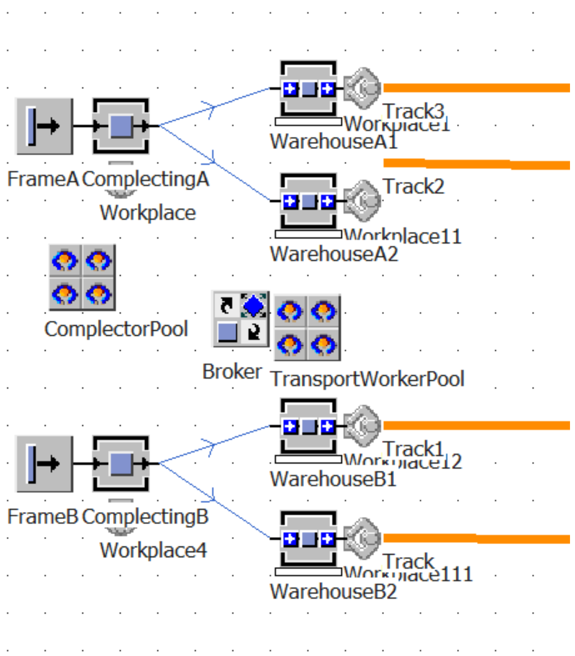

Figure 3.3 Top view of the warehouse side

The frame kitting on the trolleys was split into two stations – one for family A and the other for family B. Both stations have their own source of frames that depict the frames, in packaging, from the supplier. This was to simplify the creation of the simulation but also to a have simple comparison between the time spent for both product families. 2

workers were assigned to cover the 2 stations in order to evaluate the sub-assembly station statistics properly and ensure the kitting will not become the bottleneck of the process due to resources.

After the kitting station there are buffers for each production line simulating the frame trolley. Each buffer has a capacity of 9 pieces. The transportation is done by transport workers. As the program does not enable the simulation of trolleys as separate units, to simulate the movement of 9 frames, the capacity of the transport workers was changed so that each worker can carry 9 pieces simultaneously (Figure 3.4). With this set up the overall idea of the transport worker's work time will remain the same.

Each line was given their own transport worker as using a shared pool of workers showed that the simulation will not handle the task allocation and two transport workers will answer the same task which would have had a negative influence on the statistics as the transport workers were then waiting in production side of the simulation while the other lines were waiting for transport worker to replenish frames. Therefore, each line was allocated their own worker. This needs to be kept in mind when making analysis as the transport workers should then be analysed as one entity.

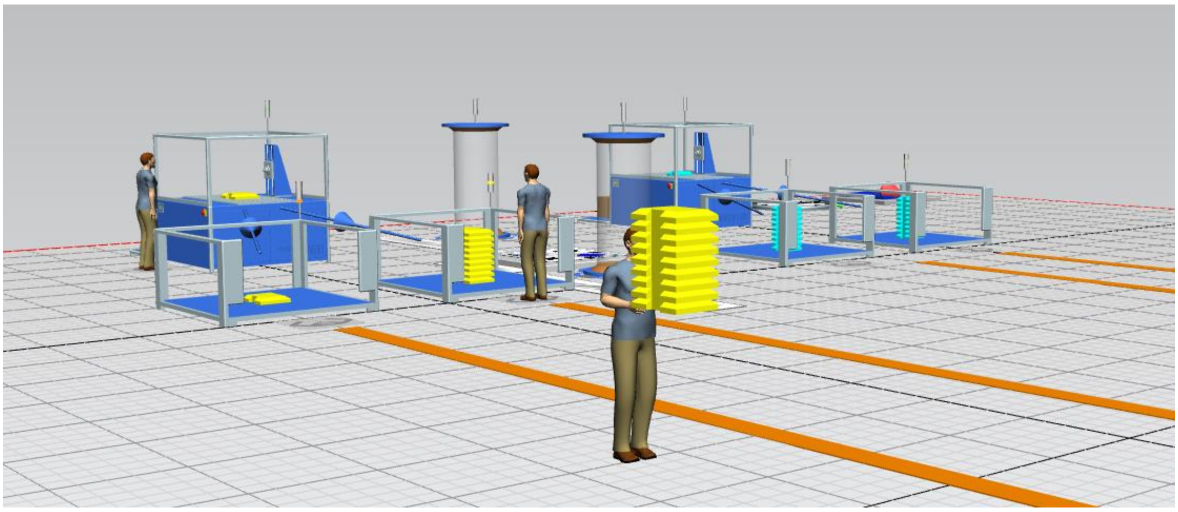

Figure 3.4 Simulation warehouse side in 3D showing transport worker with 9 pieces

3.3.2 Production side build

The production side of the simulation consists of five parts: buffer area for frames, source for carriers, sub-assembly station, main assembly station, and drain for ready products. Furthermore, there is the WorkerPool for assembly workers and a separate Broker.

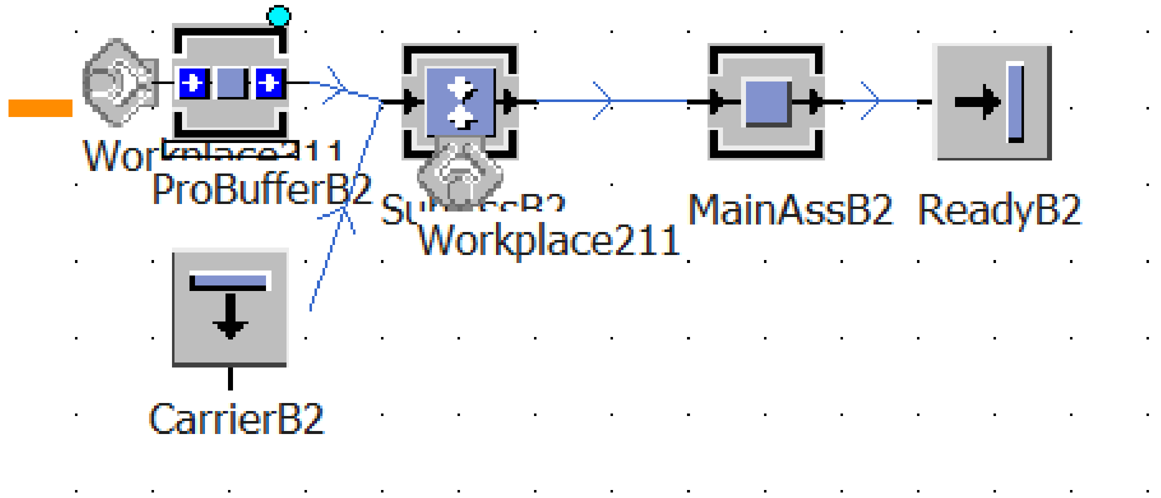

Figure 3.5 Production line 2D top view for simulation

The buffer area serves as the material replenishment trolley for frames. The buffer capacity is 9 pieces and when the buffer is empty, new material will be put in the buffer by transport workers.

For carriers, it is assumed that there is no restriction of resources and therefore, there is only set-up time. Set-up occurs after every 5 pieces for 180 seconds to show the replenishment of carriers. However, as this time is shorter than the waiting time for main assembly, then this set-up time is not seen in statistics of the as-is simulation.

Each sub-assembly station has their own production worker who is not leaving the station while waiting. This will allow us to simulate the real situation in production where the worker is assigned to their workstation. In the sub-assembly station, it is simulated that the worker attaches the frame onto the carrier; however, the name of the entity will remain as carrier due to the nature of the program.

The main assembly station is set up without a worker as optimizing the main assembly work is not part of this paper. However, having main assembly added to this simulation is important to understand the tact of the whole material flow.

The final step of the production is drain. This is the disposal site of the simulation products.

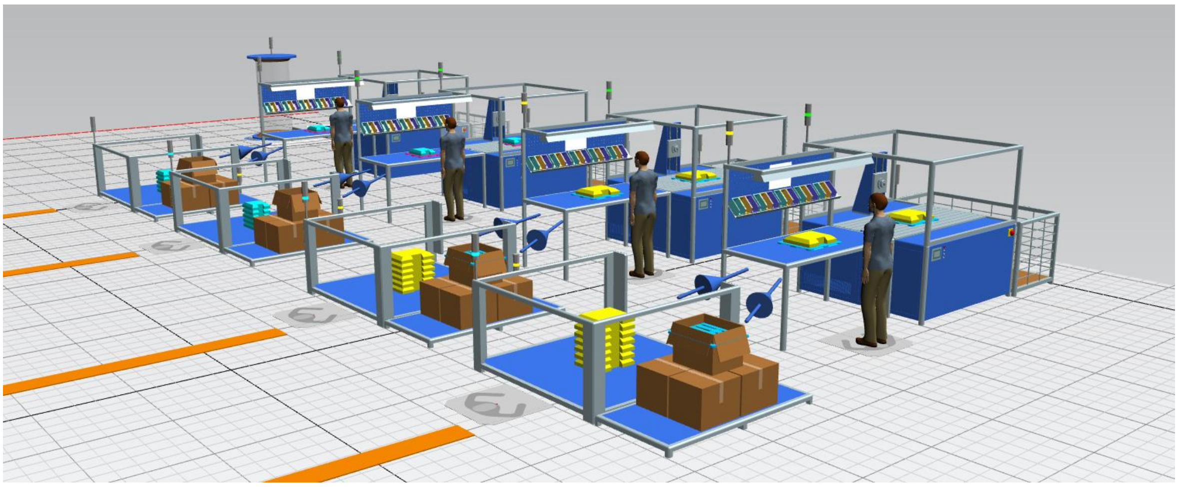

Figure 3.6 Production lines in 3D view for simulation

3.3.3 Simulation specifics

For the simulation to work in a way that would give the most realistic results some rules were needed to be set to the objects. The main parameters changed for all the objects were naming and processing times.

The frames and carriers were created as user specific parts that would reflect as closely as possible the real products. The colours were given to have a better view where the carriers and frames are in simulation. Carriers were created as container to enable placing the frame onto them and workpiece carrier box was ticked to only allow one product placement. The carrier size was taken as the assumed real measurements. The full configuration can be seen on Figure 3.7.

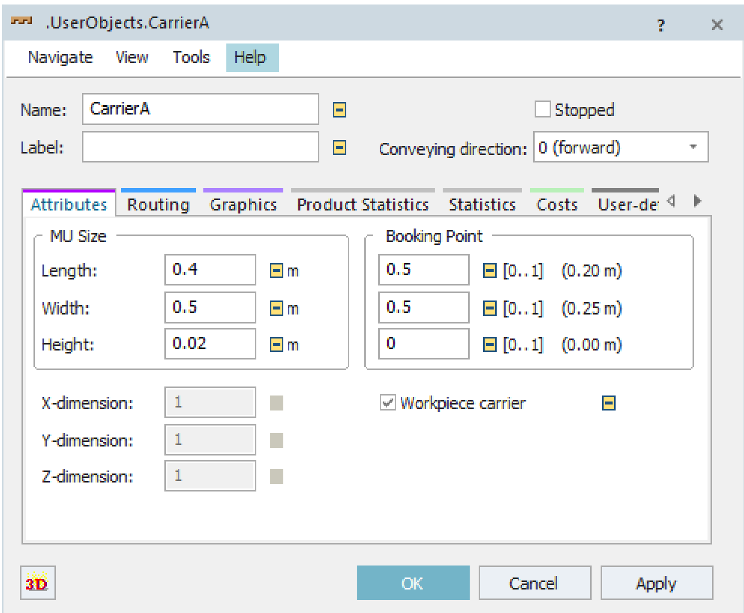

Figure 3.7 CarrierA configuration example

With the consolidated kitting station for two production line flows, an exit strategy had to be put in place for the station to divide the frames between two buffers. At first it was attempted with cyclic method where one piece was put into first buffer, second to the second, third to first and so on; however, this did not depict the real situation well enough and therefore, cycle of filling up the first buffer with 9 pieces and only then moving to the second buffer was set up.

For the transport workers a maximum dwelling time was given to simulate the real-life cases where the transport worker is taking some time to find the correct trolley or notice the signal from production. The time was estimated to be maximum 2 minutes and therefore maximum 2-minute dwelling time was added to each transport worker.

In the real production, the frames are replenished based on a signal from production, this had to be considered in the simulation as well. Without any signal and programming, the transport workers were picking up the frames from warehouse buffer and bringing them to the production side while the buffer in production was still full. This created a situation where all the transport workers were standing in production waiting for the buffers to empty to give away all the frames in their hands.

To avoid this situation the following rules were implemented: frames can enter the production buffer only when buffer in production is empty and frames can leave the warehouse buffer only when signal from production has been given. This was done with entrance and exit controls of warehouse and production buffers.

The code was written in SimTalk2.0 which is the programming language used in Tecnomatix Plant Simulator. SimTalk2.0 helps to access all attributes and methods available in the program and configure the simulation to fit the user’s needs. [20]

The entrance and exit controls both are manipulated with the entrance and exit locks of the buffers based on the number of frames in production buffer or the previously added locks statuses. Both codes can be seen on Figure 3.8 and Figure 3.9.

```
if ProBufferB2.numMU>0 then
    ProBufferB2.entrancelocked:=true
    @.move
    waituntil ProBufferB2.numMU=0
    ProBufferB2.entrancelocked:=false
end
```

Figure 3.8 Exit control of production buffer

```
If ProBufferB2.entrancelocked=true
    WarehouseB2.exitlocked:=true
    waituntil ProBufferB2.entrancelocked=false
    WarehouseB2.exitlocked:=false
    @.move
end
```

Figure 3.9 Entrance control of warehouse buffer

Using the entrance and exit locks as manipulators created an issue where the locks were either on or off when stopping the simulation based on the state of the simulation. To start the new simulation run with all locks open, an extra method was written to remove all locks. This method will be running only once in the beginning of each simulation run manually by the user of the simulation. The method resets all the locks to false. This part of the method can be seen in the beginning of the code in APPENDIX 1.

3.4 Simulation analysis

The analysis of the simulation will be done based on the statistics received directly from Tecnomatix Plant Simulator. The statistics come in form a report gathering all objects data together. The simulation was run for 10 hours with statistics being taken starting from 2nd hour; therefore, all the statistics are reflecting an 8-hour period. The analysis will be done keeping in mind the goal of reducing waste in the sub-assembly process. All the times in analysis are presented in format hh:mm:ss.The simulation was run for 8 hours with no breaks and as a result, a total of 192 products from family A and 160 products of family B were produced. As can be seen in Table 3.5 there is equal number of products from both lines within the same family.

Table 3.5 Drain statistics per line

Object	**All Types**	**CarrierA**	**CarrierB**
ReadyA1	96	96	0
ReadyA2	96	96	0
ReadyB1	80	0	80
ReadyB2	80	0	80

3.4.1 Portions of states analysis

The working, waiting, and blocked time analysis data comes in statistic report as a table that also graphically shows the portion of working (green), waiting (gray), and blocked (yellow) times. The portions of states can be seen in Figure 3.10.

One of the main wastes that can be identified with the portions of states analysis is the waste of waiting. The waiting can appear in two different ways: workers waiting on machinery or material, or machinery standing idle. [21]

Portions of the States

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
WarehouseA1	0.00%	0.00%	9.24%	90.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
FrameA	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CarrierA1	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
SubAssA1	23.33%	0.00%	0.00%	76.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
MainAssA1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ReadyA1	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ProBufferA1	0.00%	0.00%	88.54%	11.46%	0.00%	0.00%	0.00%	0.00%	0.00%	
ComplectingA	20.62%	0.00%	0.07%	79.30%	0.00%	0.00%	0.00%	0.00%	0.00%	
WarehouseA2	0.00%	0.00%	9.50%	90.50%	0.00%	0.00%	0.00%	0.00%	0.00%	
ReadyA2	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
MainAssA2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
SubAssA2	23.33%	0.00%	0.00%	76.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
ProBufferA2	0.00%	0.00%	88.54%	11.46%	0.00%	0.00%	0.00%	0.00%	0.00%	
WarehouseB1	0.00%	0.00%	7.68%	92.32%	0.00%	0.00%	0.00%	0.00%	0.00%	
WarehouseB2	0.00%	0.00%	7.52%	92.48%	0.00%	0.00%	0.00%	0.00%	0.00%	
ComplectingB	16.72%	0.00%	0.24%	83.04%	0.00%	0.00%	0.00%	0.00%	0.00%	
FrameB	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
MainAssB2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
SubAssB2	19.44%	0.00%	0.00%	80.56%	0.00%	0.00%	0.00%	0.00%	0.00%	
ProBufferB2	0.00%	0.00%	88.75%	11.25%	0.00%	0.00%	0.00%	0.00%	0.00%	
MainAssB1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ReadyB1	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CarrierB1	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
SubAssB1	19.44%	0.00%	0.00%	80.56%	0.00%	0.00%	0.00%	0.00%	0.00%	
ProBufferB1	0.00%	0.00%	88.75%	11.25%	0.00%	0.00%	0.00%	0.00%	0.00%	
ReadyB2	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CarrierA2	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CarrierB2	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 3.10 Screenshot of the statistics report

From the first view the main assembly has the biggest working percentage which is not surprising as the main assembly has the longest cycle time in the whole flow viewed in this paper. The drains as well as sources can be ignored for the analysis as there is no working time nor are they either constantly blocked or waiting to depend on whether they are in push or pull end of the manufacturing.

When taking the average of each line for every step then it can be taken as the average result of resource usage for each step of the sub-assembly process. The average results per steps can be seen in Figure 3.11.

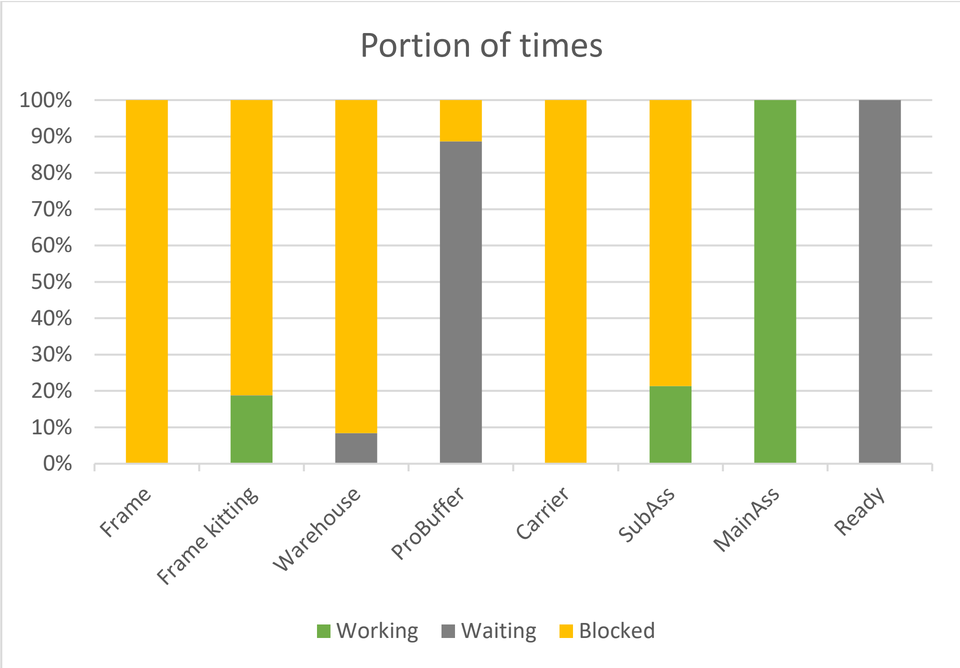

Figure 3.11 Average portions of states in the simulation

From the average view it can be said that the resource usage for kitting and sub-assembly is not reasonable and needs to be optimised as both stations are blocked for majority of the time due to the main assembly being the blocker in this process. As the main assembly cycle time cannot be changed in this process view, then the resources and activities should be optimised towards the actual needs of the main assembly. Furthermore, the 100% blocked states for Frame and Carrier show that there is no shortage of materials and 100% waiting state for Ready shows there is no blockage – these states assure that the analysis needs to be done with processes not with source or drain.

For kitting, it needs to be kept in mind that in the simulation there were separate stations for both product families. In real production, the station is used for all the products and kitting is done as requested. However, even if the kitting stations would be united, then the total working portion would be less than 50% of the total time. This means the kitting station is still underused and that could be investigated. On the other hand, it should be mentioned that the same station also does kitting for other materials needed for main assembly and therefore, the stations working portion might be much higher. For this paper it will be considered that the optimisation is done for only the sub-assembly process and the goal is to optimise all steps related to that process.

The waiting portion of kitting stations can also be seen in the waiting for services and parts statistics in Table 3.6. The waiting time is more than 75% for both of the stations. The mean value of the waiting time is from 20 to 30 minutes which shows the average time the worker could have performed other tasks.

Table 3.6 Waiting for services and parts in frame kitting (Complecting)

Object	**Waiting for Services and Parts**	**Count**	**Sum**	**Mean Value**	**Standard Deviation**
ComplectingA	76.33%	12	6:06:23.7711	30:31.9809	12:50.3607
ComplectingB	75.04%	18	6:00:12.4718	20:00.6929	22:57.3433

The sub-assembly station has the lowest working portion out of the 3 working stations (kitting, sub-assembly and main assembly). This is created by the cycle time difference between sub-assembly and main assembly. Furthermore, this shows that it is not sensible to have a separate sub-assembly station for each production line as there is not enough work to be done for a separate station and worker to be waiting.

Looking into the waiting times, then it is clear the longest waiting time is in the frames buffer in production. This shows that the frames are waiting in production for a long time with no usage. Following the "just in time" concept it should be investigated whether there is a possibility to optimize the number of frames brought into production at once. [22]

3.4.2 Transportation analysis

The transportation analysis will be performed based on the transport workers mediation and dwell times. The mediation time shows how long it took the transportation worker to fulfil the task of transporting frames from one buffer to another, and the dwell time can be counted as statistics about the attention mistakes of the workers. Out of these statistics it is also possible to find the amount of times the workers had to move between warehouse and production during this 8-hour simulation run.

The configuration of the transport worker was left as default in the program. The default configuration means the efficiency of the worker is 100% and the speed of the worker is 0,9m/s. The distance between warehouse and production was set to 150 meters. The Z-dimension was set to 9 as this allows the worker to pick up a maximum 9 frames simultaneously.

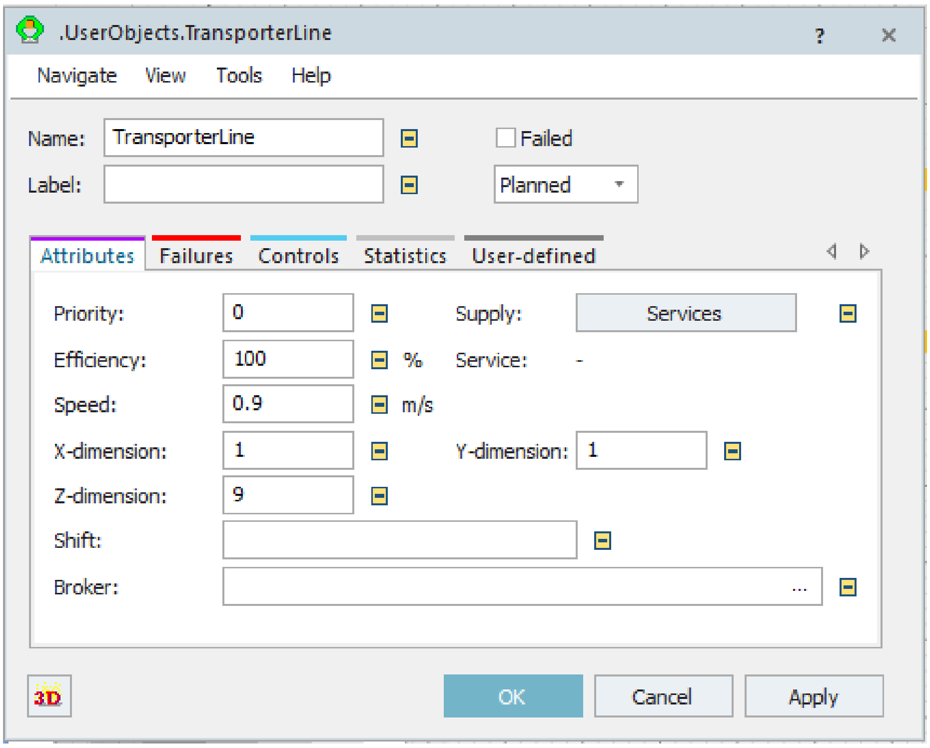

Figure 3.12 Transport worker configuration

The mediation time of the transport workers shows how many signals in total the workers received during the 8 hours of simulation run and how long, on average. the procurement task took. From the Table 3.7 it can be seen that the number of signals was either 12 or 10 depending on the product family and the average mean value is about 3 minutes and 20 seconds. This shows only one-way transportation time and therefore the same time is spent by the worker to walk back to the warehouse. When calculated into percentage from the total time of the simulation run then the valuable transporting time is only around 7 percent per line. Even when the transport workers would be counted as one worker then the valuable time for sub-assembly process transportation would total to around 28% and the total working time would be double of that.

Table 3.7 Mediation time of transport workers

Services	**Count**	**Sum**	**Mean Value**	**Transporting % out of total time**
TransporterA1	12	40:16.2489	3:21.3541	7.65%
TransporterA2	12	39:24.3836	3:17.0320	7.65%
TransporterB1	10	33:27.6484	3:20.7648	6.48%
TransporterB2	10	33:02.6799	3:18.2680	6.48%

The dwell time was set to peak at 2 minutes for all transportation workers. This ensured the workers will not dwell at the warehouse station too long, but it did add expected dwell time for the simulation to be closer to real transport workers. The dwell count is twice of the mediation count as the dwell time is counted before the worker picks up the frames and after they have returned to the warehouse.

Table 3.8 Dwelling time of transport workers

Services	Count	Sum	Mean Value	Standard Deviation	Minimum	Maximum
TransporterA1	24	27:32	1:08	1:01	3.8670	2:03.8670
TransporterA2	24	26:36	1:05	1:01	2.5337	2:02.5337
TransporterB1	20	22:54	1:08	1:01	2.7000	2:02.7000
TransporterB2	20	23:20	1:10	1:01	4.0333	2:04.0333

It could be considered overall that transportation is not a valuable activity for the production; however, it is required activity. As the activity itself cannot be removed from the process then other means of optimising or automating this activity must be investigated.

3.4.3 Human resource analysis

The process involves 3 types of workers: warehouse workers doing frame kitting (complectors), transport workers, and assembly workers.

The warehouse workers who are kitting the frames have utilisation rate of 37,5% of the total simulation run. As the worker pool for both kitting stations was the same then the resource analysis is done based on the service. The data can be seen in Table 3.9, where the count shows how many times the workers had to go through the kitting process (counted by number of frames), the sum of time spent working, the mean value per one process run and the percentage of the total simulation run. The utilisation of warehouse workers can be counted as low. In the real production environment these workers are working on other material replenishment as well and therefore, their utilisation might be higher; however, the utilisation of these workers can be increased inside the sub-assembly process as well.

Table 3.9 Warehouse worker (complector) activity time

Services	Count	Sum	Mean value	% of simulation run time
Complector	359	3:00:46	30.25	37,5%

The transport workers efficiency was investigated in previous point and it was discovered that there is capacity overestimation as the transportation time only took in total 28% of the whole simulation run combined for all four workers. It should be considered that additionally the same amount of time took the workers to return to the warehouse. Furthermore, to calculate the total resource usage the dwelling time needs to be added as well. If all the times are considered, then the total % of used time by transportation workers is 83%. This shows that the utilisation of transport worker is high; however, the valuable time out of it is only the pure transportation time that was calculated only up to 28% of the total time of simulation run. The Table 3.10 shows all the transport workers activity times and the value adding total time is highlighted with green and the non-value adding times of dwelling and returning are highlighted red.

Table 3.10 Transport workers total activity time

Services	**Sum of transporting time**	**Sum of dwelling**	**Sum of return time**	**Total time of activities**	**% of simulation run time**
TransporterA1	00:40:16	00:27:32	00:40:16	01:48:04	23%
TransporterA2	00:39:24	00:26:36	00:39:24	01:45:24	22%
TransporterB1	00:33:27	00:22:54	00:33:27	01:29:48	19%
TransporterB2	00:33:02	00:23:20	00:33:02	01:29:24	19%
Total	02:26:09	01:40:22	02:26:09	06:32:40	83%

The same logic is used for sub-assembly station workers statistics as for the warehouse workers and the resource analysis is done based on service in total and then the individual analysis for each assembly worker can be done based on the assembly station utilisation as the worker is initially working the same amount as the station.

When looking into the overall service utilisation, then it is 86% of the total time of the simulation run which is a good result. However, it must be considered that this service is delivered by 4 workers which makes the utilisation per worker to around 19-23% as can be seen in Table 3.11 showing the sub-assembly station's working portion. The total working time of all the sub-assembly stations is 6:50:40 which is not equal to the servicing total time. The discrepancy between the two times comes from the beginning of the simulation where the assembly workers were already in workstations, but the frames were not delivered yet and the station was not working.

Table 3.11 Assembly worker activity time

Services	**Count**	**Mean Value**	**Sum**	**% of simulation run time**
Assembly	353	1:10.0000	6:51:27	86%

Table 3.12 Sub-Assembly working portion

Object	Portion	Count	Sum	Mean Value
SubAssA1	23,33%	96	01:52:00	1:10.00
SubAssA2	23,33%	96	01:52:00	1:10.00
SubAssB1	19,44%	80	01:33:20	1:10.00
SubAssB2	19,44%	80	01:33:20	1:10.00

The most distinguishable waste in sub-assembly station is the un-used time of the workers as well as the replenishment of carriers by the same worker which is not seen in the simulation. The carrier replenishment is an extra activity requiring the assembly worker to leave the workplace after every 5 cycles to bring new carriers. For this activity, the time is not that important as the activity is non-value-adding and therefore should be eliminated or automated.

Total amount of workers needed for this process based on the simulation results and considering the real situation is depicted in Table 3.13.

Table 3.13 Total workers count and their utilisation %

Worker	Count	Utilisation %
Warehouse worker	1	37,5%
Transport worker	1	82%
Assembly worker	4	21%

Overall, the largest waste in this process is the low utilisation of human resources and the high waiting time for all processes before main assembly.

4 SUB-ASSEMBLY FLOW CHANGES

The sub-assembly flow will be re-evaluated with the inclusion of all the upcoming changes and after that the improvement options will be proposed.

4.1 Changes in the production process

4.1.1 Adding automated main assembly

First the automated assembly was added for family A and then for family B. It will be assumed that the main assembly cycle time is reduced by 50% from automating the assembly process. The cycle times for both products can be seen in Table 4.1.

Table 4.1 SimData automated line cycle times

Product family	**Time**	**Unit**
Family A	150	s
Family B	180	s

As the automated line will be 50% more productive, it can be assumed that the number of manual assembly lines will be reduced. The reduction will be made in way that the total output of the production will remain the same. However, as the factory is producing the products mixed and the changeover of the manual and automatic line production can be done with ease. Therefore, further analysis is done in the following set up: one manual assembly line for product family A, one manual line for product family B and an automated line will be analysed that can produce either A or B but only one per simulation.

In the simulation the main assembly cycle time will be controlled by the variable "*pro*" that is changed according to the product family. For the variable value of 1 the cycle time for product A is used and the variable value of 2 represents the cycle time of product B. The variable set up can be seen in Figure 4.1 and the input in code in APPENDIX 1.

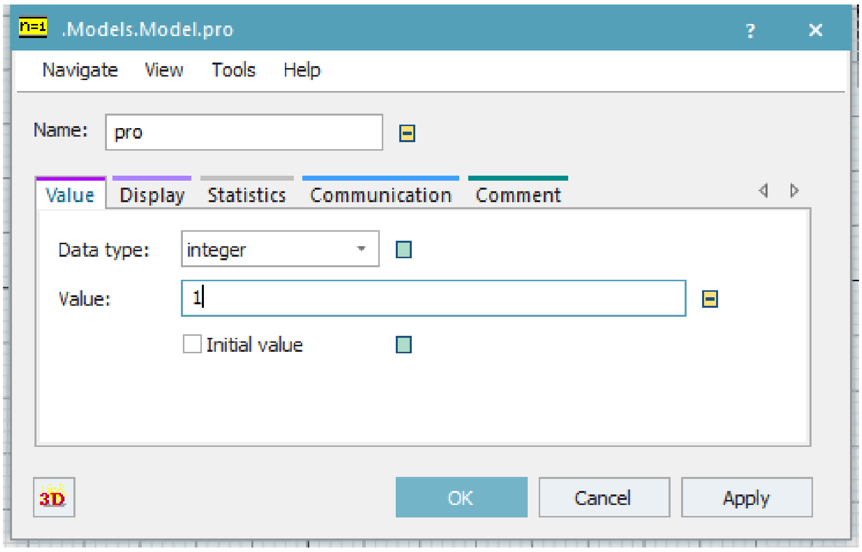

Figure 4.1 Variable to control what is produced on automated main assembly

Family A

In the first run, one of the manual main assembly lines for family A (line A2) was replaced with the automated assembly line. The production was run for 8 hours and the portion of states can be seen in Table 4.2. The main differences in portions are in production where it is detected that ProBufferA2 is waiting for 100% and this means the waiting for parts time for SubAssA2 should be reviewed for increased waiting time as well. The sub-assembly station working time is increased by 50% which was expected.

Table 4.2 Portions of states family A

Object	**Working**	**Waiting**	**Blocked**
ComplectingA	33.02%	0.21%	66.77%
WarehouseA1	0.00%	12.06%	87.94%
WarehouseA2	0.00%	20.55%	79.45%
ProBufferA1	0.00%	89.58%	10.42%
ProBufferA2	0.00%	100.00%	0.00%
SubAssA1	23.33%	1.14%	75.52%
SubAssA2	45.94%	3.79%	50.28%
MainAssA1	100.00%	0.00%	0.00%
MainAssA2	100.00%	0.00%	0.00%

Looking into the waiting time for parts, there is a slight increase of waiting for sub-assembly station between A1 and A2. This is most likely caused by the transportation worker not being able to deliver the frames quick enough to the station. As it can be seen, the mean value of waiting is less than a minute and it only happened 21 times. It must be considered; however, that the waiting time in the beginning is already counting to 10 minutes as the warehouse buffer is filled for A2 as the second buffer. Therefore, the mean value of actual production time waiting time will be much less and can be ignored.

Table 4.3 Waiting for parts comparison between sub-assembly stations for family A

Object	Waiting for Parts	Count	Sum	Mean Value
SubAssA1	1.14%	1	5:28.9750	5:28.9750
SubAssA2	3.79%	21	18:10.7908	51.9424

Family B

Replacing one of the main assembly lines with the automated assembly line for family B provides the portions of states results as shown in Table 4.4. The line of B2 was changed to automated line. The line B1, which was not automated, keeps similar results to the as-is simulation and the impact of automated line can be seen when lines B1 and B2 are compared. The sub-assembly station working portion has increased from 19% to 38%, which is a 50% increase. This was predictable change as the main assembly is 50% faster for automated line. For the kitting station in warehouse, the increase is from 19,90% to 29,17%.

Table 4.4 Portions of states family B

Object	Working	Waiting	Blocked
ComplectingB	29.17%	0.53%	70.30%
WarehouseB1	0.00%	10.53%	89.47%
WarehouseB2	0.00%	19.13%	80.87%
ProBufferB1	0.00%	90.00%	10.00%
ProBufferB2	0.00%	89.38%	10.63%
SubAssB1	19.44%	1.14%	79.41%
SubAssB2	38.33%	2.09%	59.58%
MainAssB1	100.00%	0.00%	0.00%
MainAssB2	100.00%	0.00%	0.00%

Overall, adding the automated assembly line only affects the working time portion of some stations and therefore the optimization can be done based on same criteria as for manual assembly lines.

4.1.2 Adding automated packing line

According to the as-is production process model, the carriers are freed after the final assembly step and then brought back to the beginning of the sub-assembly station. As both processes and all processes between are in the same production hall, the biggest change with the coming automated packing line is the movement of the carriers.

The automated packing line will be installed in the warehouse and therefore the carriers will be freed in the warehouse near the source of frames. To continue the current sub-assembly process, the carriers should be transported the same way as frames to the production hall. This would more than double the work of the transport workers as well as creating more waste by moving the carriers and frames from one place to another for kitting. The possible improvements for eliminating this waste would be to kit the carriers and frames together already in warehouse to cut the transportation need as well as improve transportation overall.

4.1.3 RFID tag writing capabilities

For all automated processes the chosen product identification method is RFID tag. The tag is attached to the carrier and will be moving with the product throughout the whole production cycle.

The product information can be found on a label that is attached to the product in the sub-assembly onto the side of the frame as a temporary label and is then placed onto the front cover in final assembly. The labels are using the barcode system and are scanned in every step of production with a handheld scanner.

The need for using RFID tags in automatic processes comes from the technological differences between barcode and RFID systems. Both systems belong to Automatic identification and data capture (AIDC) systems which categorises all the auto-ID procedures into five sections: barcode system, biometric systems, RFID, smart cards, and optical character recognition. [23] All the procedures have their own field of use and advantages and disadvantages.

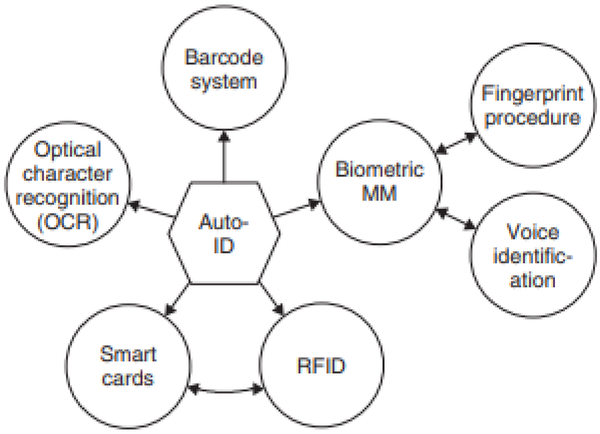

Figure 4.2 Auto-ID procedures overview (source: Finkenzaller, 2010) [23]

The difference between barcode system and RFID is mainly about the speed of readability as well as reusability. The differences that Finkenzaller has identified are brought out in Table 4.5. Next to these differences the reusability or possibility to re-write the information and add the information without any external information storage system is one of the biggest advantages of using RFID instead of barcodes for automation. Furthermore, even though Finkenzaller grades the machine readability for both systems as "good" in automated machinery, reading the RFID tag is cheaper and easier. For the barcode reading automatically a camera is necessary as well as the quality of the barcode label needs to be constant for one position reading – furthermore, the impact of optical covering can affect the operation. For the RFID system these constraints do not exist as the tag with data can be covered while maintaining readability as well as the process of reading the tag is much easier to organise. Therefore, the information from the barcode label needs to be transferred to the RFID tag for automated machinery but the label is kept for workers to easily identify the products when they are taken out of the system.

Table 4.5 Comparison of barcode and RFID (Finkenzaller, 2010; modified by author) [23]

System parameters	**Barcode**	**RFID**
Typical data quantity (bytes)	1-100	16-64 k
Machine readability	Good	Good
Readability by people	Limited	Impossible
Influence of (optical) covering	Total failure	No influence
Operating costs	Low	None
Reading speed	Low ~4s	Very fast ~0,5s
Maximum distance between data carrier and reader	0-50 cm	0-5 m

The RFID tags have already been attached to the carrier as one of the first steps of the automation activities. There is already one machine using the RFID tags for identifying the products. The current testing set up is choosing the tester and moving the product along based on the data written on the RFID tag. The information is written on the tag right before the product enters the test environment and the data on the RFID tag is only re-written in there. The RFID tag writing process is part of the test preparation; however, with the upcoming automatic main assembly line, this process needs to happen earlier. The RFID writing integrates with the MES through programmable logic controllers (PLC) or personal computers (PC) equipped with the application software. All the relevant relations can be seen on Figure 4.3, the communication between the RFID tag and RFID reader/writer is radio communication and all rest being digital communication using different protocols depending on the specific peripheral, PLC and PC.

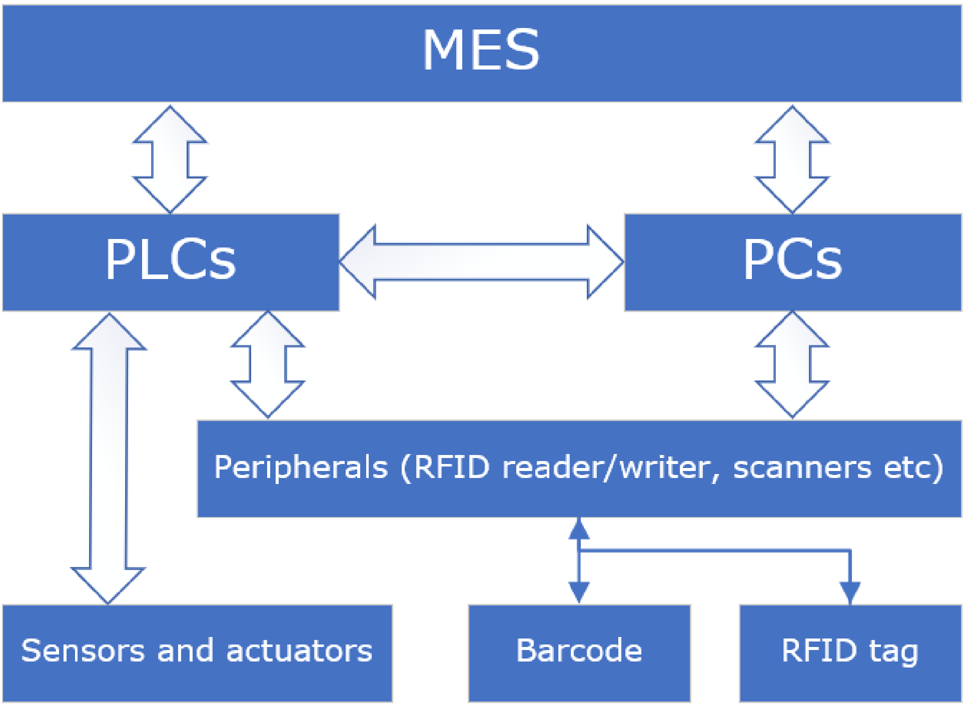

Figure 4.3 RFID technology integration with manufacturing system

Firstly, the RFID tag writing capability must be set up in the sub-assembly station belonging to the automated main assembly line. However, if the sub-assembly stations are consolidated then the writing capability must be in every sub-assembly station that is possibly preparing sub-assembly for automated main assembly.

The RFID writing set up consists of two parts: hardware and software. On the hardware side RFID writer, computer, screen, and a scanner are needed. The software for writing RFID tags will be developed in-house and must be verified before using it in production.

4.2 Improving working time efficiency

As the first improvement, the work efficiency of the kitting station and sub-assembly station is addressed. The kitting station average working portion was 31% after adding the automated line, the sub-assembly station's maximum working portion was reached with producing family A products on automated assembly line, with sub-assembly station working portion 45,94%.

The efficiency rates for both stations are low, and the carriers are released from warehouse, which indicates that it can be investigated whether it would be more efficient to compile the kitting and sub-assembly station.

To understand how many stations can be merged in total, the theoretical process time of the new station must be calculated. In the kitting station the whole process is 30 seconds per frame to place it onto the trolley. In the sub-assembly station, the same time is needed to place the frame onto the carrier. Therefore, it can be assumed that the new sub-assembly stations process time remains the same as it was before merging.

Table 4.6 New merged sub-assembly station process time

Process step	**Time**	**Unit**
Checking the carrier	5	s
Kitting frame onto carrier	30	s
Vacuuming the frame	10	s
Placing the label on the frame	10	s
Scan the label	10	s
Confirm the information	5	s

The predictable working portion for the new sub-assembly station are therefore, also the same as for the initial stations in production. As the average sub-assembly station working portion for manual assembly preparation is between 21 and 22%, and the highest working portion for automated assembly preparation is almost 46 percent, then it could be predicted that all the sub-assembly stations can be together in one station.

For simulation simplification, the differences of products were not considered anywhere but the main assembly times. In the simulation, the efficiency of the transport workers was not analysed as the transport as an activity will be focused on in the next sub-chapter. The simulation model from warehouse and production sides can be seen on Figure 4.4.

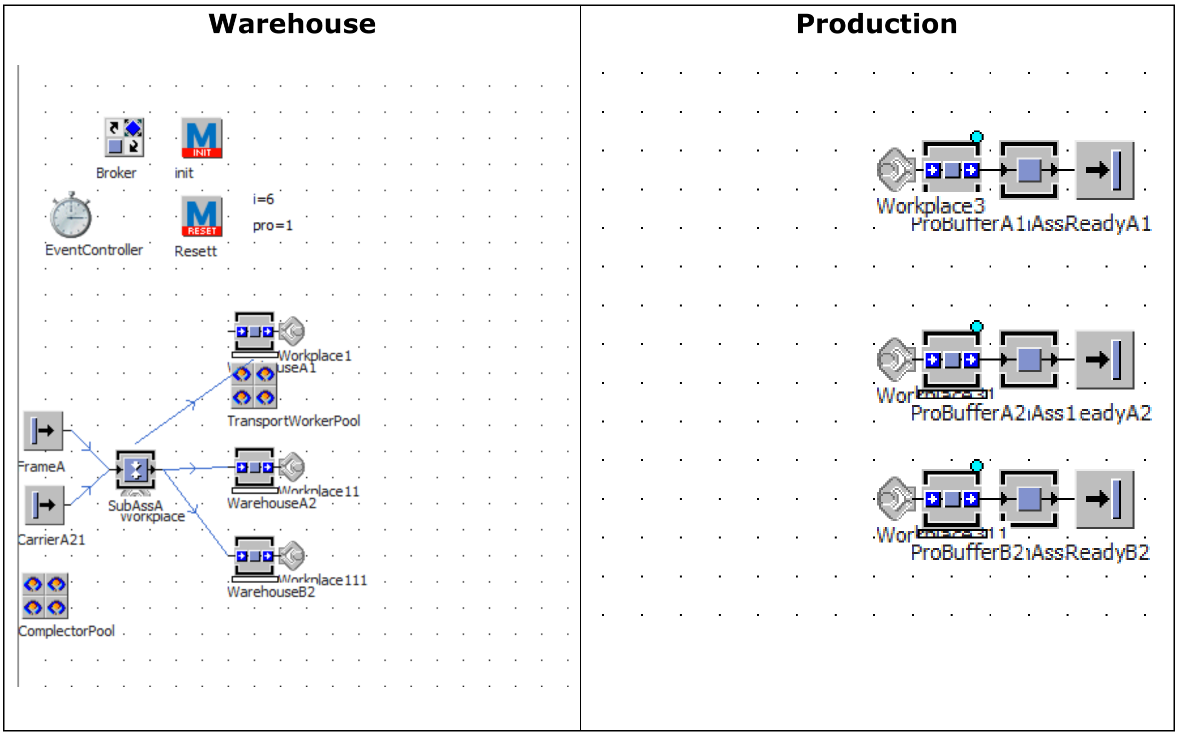

Figure 4.4 Improved top view of simulation (warehouse and production)

The simulation was run with 9 kits of carriers and frames transported on one trolley from warehouse to production. As in the as-is simulation, the transport workers were allocated for each line separately to avoid any transportation caused delays and waiting times. One of the manual assembly lines was removed for simulation purposes as the automated line reduces the cycle time of main assembly by 50% and therefore, it creates comparable data with constant production output. The simulation proved that having a single sub-assembly station for one automated and two manual lines is enough for both possible choices – automated family A or family B. The portions of times can be seen in Table 4.7. The results also prove that the working portion of the sub-assembly station can be directly calculated from the previous data that was received from the working portions of the sub-assembly stations in the production side. For example, in the case of producing family A products on the automated line, the total of working portions of the 3 sub-assembly stations (SubAssAuto, SubAssA, SubAssB) would be 88,71% (Table 4.2 and Table 4.7) which is close to the actual simulated working portion.

Table 4.7 Portion of working time with automated main assembly and merged sub-assembly

	Automated line product	
	family A	**family B**
SubAss	88,25%	81,93%
MainAssAuto	97,64%	100,00%
MainAssA	100,00%	100,00%
MainAssB	100,00%	100,00%

For the merged sub-assembly station, the proposed layout of the workstation can be seen on Figure 4.5. The proposed layout includes the workstation itself, on the left is the incoming trolley with carriers, on the right the outgoing trolley with sub-assemblies and behind the worker are two areas for pallets with frames.

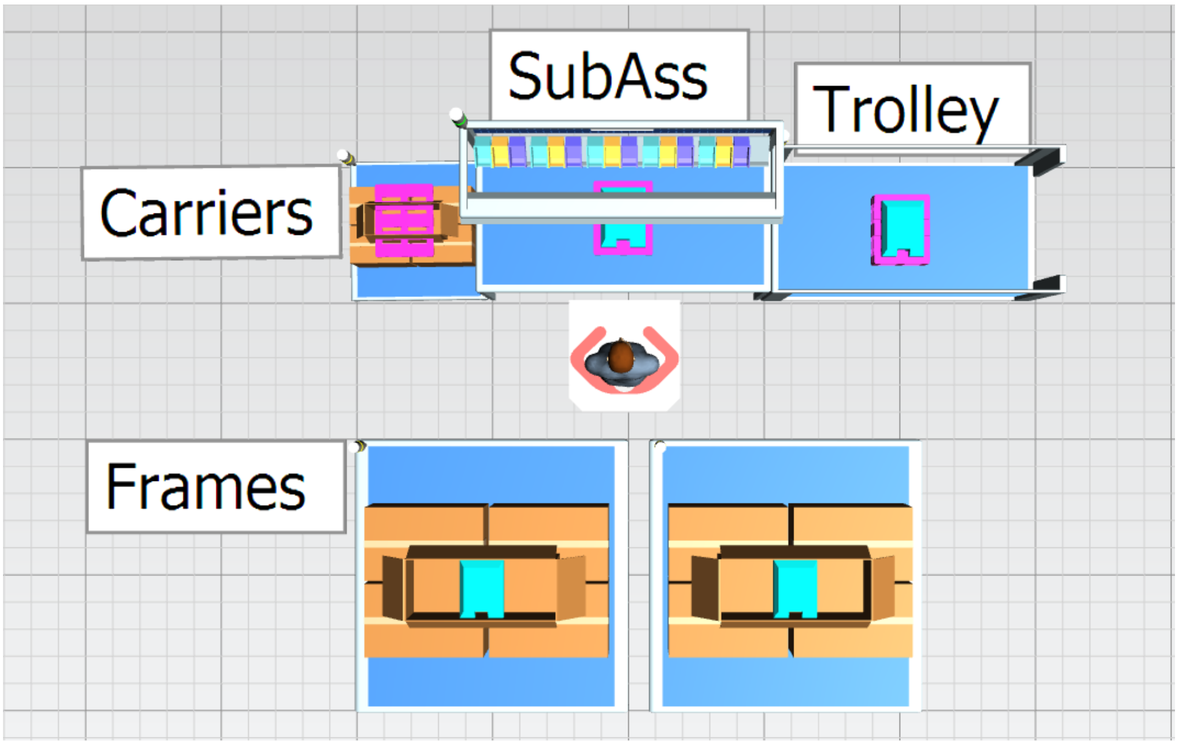

Figure 4.5 Proposed layout for sub-assembly station in warehouse

With such high working portions, it is highly unlikely that another line can be added to production with using only one sub-assembly station. A simulation was run to see how adding another manual assembly line would affect the portions. The same criteria were used for the simulation with 9 pieces transported from warehouse to production. In this run, the MainAss2 was used for either family A or B production, when automated line was producing A, then MainAss2 was producing B and vice versa. As the sub-assembly station was used 100% but the automated main assembly line working portion was between 70-75% then it was tested whether the reason can be in sub-assembly station being overbooked (Table 4.8 Working portions of stations with 3 manual assembly lines) Running the simulation with two sub-assembly stations proved that the total need of sub-assembly stations is more than 100%; however, both stations would be used only a small amount over 50% which is not efficient. Therefore, in case more manual main assembly lines are installed, the actual work time should be observed, and it must be evaluated whether to add another workstation or another solution can be found.

Table 4.8 Working portions of stations with 3 manual assembly lines

	One sub-assembly station		Two sub-assembly stations	
Automated product	**family A**	**family B**	**family A**	**family B**
SubAss1	100,00%	100,00%	53,44%	51,77%
SubAss2	N/A	N/A	53,44%	51,91%
MainAssAuto	70,83%	74,34%	98,06%	100,00%
MainAss1	100,00%	100,00%	100,00%	100,00%
MainAss2	100,00%	100,00%	100,00%	100,00%
MainAss3	100,00%	100,00%	100,00%	100,00%

4.3 Improving production cost

Currently the kit of carrier and frame only moves on the assembly conveyor and does not need to be placed on trolley and moved from one area to another for long distances. Therefore, there is a chance to design a new trolley or if possible, re-use some other trolley for that purpose.

For production cost improvement, the desired process would have the maximum number of products produced with minimum effort. As most of the variables in the process are fixed then the maximum efficiency needs to be reached by varying the ones that can be changed. The number of kits fitting on one trolley will be varied from 1 to 20 and the working portion of each station and output of each line will be observed.

The trolley capacity is controlled with variable *i* which set up can be seen on Figure 4.6 and the way the variable is used to control the capacity of the buffers representing trolleys and the transport worker can be seen in APPENDIX 1.

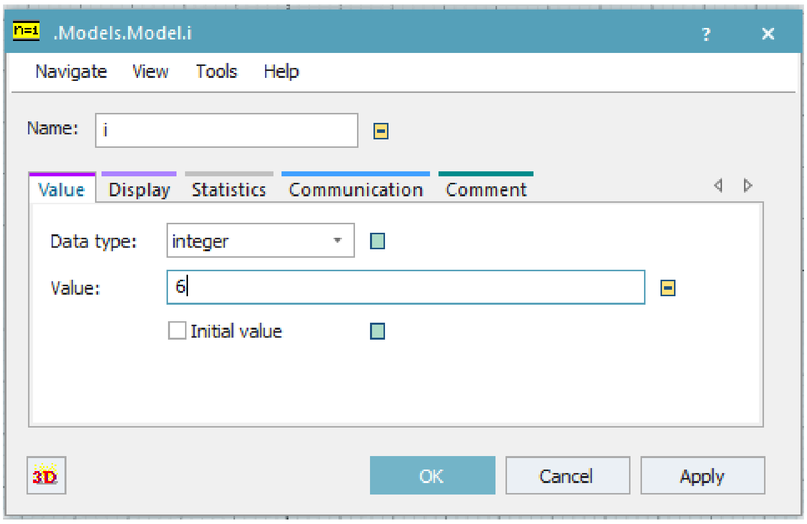

Figure 4.6 Variable for trolley capacity control

The one-piece flow is analysed separately due to its major difference from the rest of the received data. The working portions can be seen in Table 4.9. The only 100% working portion is for manual assembly line for family B products. The working portion for the one-piece flow is directly related to transportation and cycle time of the main assembly as the transportation takes more time than the main assembly and the signal for new kits is only sent out when the buffer in production is empty. Therefore, the kits do not arrive to the production area fast enough. This proves that one-piece flow is not optimal and should not be considered in further analysis.

Table 4.9 One-piece flow working portions and outputs

	Automated line product	
Automated product	**family A**	**family B**
SubAssA	60,08%	60,08%
MainAssAuto	43,44%	52,08%
MainAssA	87,50%	87,50%
MainAssB	100,00%	100,00%
Output (PCS)		
AutoA	83	83
ManA	84	84
ManB	80	80

For the rest of the trials, the results show that the working portion of the MainAssA and MainAssB – both manual lines is 100% and the output is maximum of the possible – 96 pieces for family A and 80 pieces for family B. Therefore, the focus is put on analysing the working portions of sub-assembly station and the automated main assembly line. The full results can be seen in APPENDIX 2. Next to the working portions, the output of the automated line shall be considered.

For the outputs, the maximum number is desired; therefore, the close to maximum results are brought out and can be seen on Table 4.10. The results that fall into the range for only one product family are highlighted as yellow and the results that are in range for both for the same trial are highlighted as green. The results show the most optimum quantity on the trolley falls between 9 to 14 pieces.

Table 4.10 Maximum output for family A and B automated line

Qty on trolley	**8**	**9**	**10**	**11**	**12**	**13**	**14**
AutoA	186	187	188	188	189	189	188
AutoB	160	160	160	160	160	160	159

Next step is to find most the efficient working portion for sub-assembly and main assembly in this range. The efficiency must be the best in this range across the family A and family B trials. The working portions of the sub-assembly and automated main assembly station are displayed in Table 4.11, the product that was produced on automated line is shown in parenthesis after the station name. The most efficient choice will be the one where the working portion of stations is the lowest while the output the highest as this will be the point where lowest effort results in highest output. The lowest average working portion in the selected range is at quantity of 10 pieces per trolley. The average working efficiency is decreasing even further with smaller number of kits per trolley; however, this also brings the decrease in output as seen above.

Table 4.11 Working portion and average of the portion

Qty on trolley	**8**	**9**	**10**	**11**	**12**	**13**	**14**
SubAss (A)	87,26%	88,25%	88,78%	89,54%	90,71%	90,75%	92,24%
MainAssAuto (A)	97,05%	97,64%	97,75%	97,61%	98,52%	98,71%	97,87%
SubAss (B)	81,67%	81,93%	82,09%	82,40%	84,39%	83,58%	86,12%
MainAssAuto (B)	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	99,63%
Average	91,50%	91,96%	**92,16%**	92,39%	93,41%	93,26%	93,97%

In conclusion, the highest output with the lowest effort, in this case working efficiency, is reached at 10 kits per trolley which is therefore, the most cost-efficient choice.

4.4 Improving automation level of inhouse transportation

After improving the process and choosing the amount of kits needed to be transported in one go, the transportation itself needs to be optimized as well. For transport there are a number of possibilities that can be chosen from. Firstly, the internal transport systems need to be compared and after that the most suitable must be chosen while keeping in mind the goal of automation.

Transportation method analysis

The three most common internal transportation systems will be compared with their subcategories based on the following criteria. Firstly, the basic specifications are compared: price, speed, and payload. Secondly, the difficulty of implementation and maintenance is described. Lastly, the solution must be feasible for the factory to implement; therefore, the possibility of installation or implementation is analysed.

The main systems of internal transportation are manual transportation, conveyors and robots. For manual transportation, the information is gathered internally as the current as-is set up has this method of transportation in place. The conveyors need to be considered in two different options – on the floor and under the ceiling – the conveyors specifications are taken from Bosch Rexroth catalogues. [24] For robots, two types will be analysed – automated guided vehicles (AGV) and automated mobile robots (AMR). The specification for AGVs will be taken based on Toyota TAE050 HD+ line follower [25] and for AMRs the specification of MiR100 AMR will be used [26]. All the prices will be taken from several quotations and experience of the author and will be shown as approximate assumable price for the system. The salary for the transport worker is taken from Statistics Estonia salary comparison website and the median salary of support worker in factory in Estonia will be used.

The difference between AGVs and AMRs is the main way they detect the route they need to move on. AGVs work based on following signifiers such as tracks, lines, magnetic tape, wires, etc to navigate, these detectors will be fixed on the route and need installation and maintenance. The AGV cannot move outside of the route and therefore, lacks in flexibility. On the other hand, AMRs are working based on surrounding inspection and therefore, the route is programmable and the AMR can detect its environment itself as well, in case of an obstacle, AMR will not stop to wait until the obstacle is removed but can go around the obstacle and keep on moving. This makes AMRs more dynamic and provides more opportunities in their use. [27]

The full analysis can be seen in APPENDIX 3. The main constraint that needs to be considered for the factory is the flexibility. The factory is changing quite often and with new technological advantages, the lines set up, placement, and the number of them can change often. For this reason, the future transportation solution needs to be as flexible as possible while enabling stabile manufacturing process. Out of the 5 choices, the two that would fit the most for this process and set up would be the manual transportation and usage of AMRs. As the goal is to improve the transportation automation level and it was analysed before that transportation as an activity is considered waste [21] then the choice of way-forward is AMRs.

Choice of AMR

There are several companies on the market offering AMRs and the market keeps expanding with each year as the technology is developing further. The choice of AMR will be made in two steps. Firstly, the company or platform of AMRs is chosen and then the specific set-up of the AMR will be chosen.

The main criteria for the service provider are the choice range within the platform, the fleet management availability and flexibility, the service availability in Estonia, and the additional application availability. More detailed, the two most important criteria to assess firstly are the availability of ESD protection and the biggest dimension of the AMR must not be over 1 meter for possible movement around the routes. There will be three providers compared: Mobile Industrial Robots (MiR), Omron and Otto.

Table 4.12 Comparison of AMR providers

	MiR [28]	**Omron** [29]	**Otto** [30]
ESD protection	Yes	Yes	Not specified
Suitable models	MiR100, MiR200, MiR250	LD 60 / LD 90	Otto 100
Dimensions	890x580x352 mm	699×500×383 mm	740x550x301 mm
Pay/towload range	100-500 kg	60-90 kg	100 kg
Fleet management	MiR Fleet	FLOW Core	OTTO Fleet Manager
Service availability in Estonia	Yes	No	No
Add-ons on offer	Yes	No	No

Out of the three compared providers, the most suitable one is MiR. That choice is based on fitting in both criteria set before: having ESD protection as well as being dimensioned suitably. Furthermore, the range of payload and towload of MiR is the largest which provides the largest choice later for different AMRs from the same company. One of the negative sides of all the providers is the fleet management as every provider has their own fleet management system and therefore, integrating different AMRs would be difficult in the future. The availability of service and add-ons is a positive addition to MiR.

In Ericsson Supply Site Tallinn AMRs have been used before as well and they are all from MiR which shows the company already has experience with the provider. MiR offers a wide variety of different AMRs that have different specifications and therefore there is still a room for choice between different ones. As all the robots from this provider work in the same fleet management system then the pre-existing AMR’s type is not that important, and the choice can be made between whichever AMR from the selection available by MiR.

The choice will be made by the ability of transporting 10 kits on a trolley at once with the lowest cost. Therefore, the main technical specification that is needed to pay attention to is the payload or the towing load. The total weight needed to be transported must be calculated separately for family A and family B products. The heaviest product will then be the baseline of what will need to be considered for AMR payload.

The total weight of 10 kits of family A sub-assemblies weigh 10*(7+8) = 150(kg) and for family B it is 10*(10+15) = 250(kg). A trolley for 10 kits can be assumed to weigh 30kg which brings the heaviest full trolley of family B sub-assemblies to a total weight of 280kg. Therefore, the chosen AMR type needs to be able to carry or tow at least 280kg.

MiR has three available basic AMRs in selection and their payload and towing load are shown in Table 4.13. None of the three AMRs can transport the trolley without towing it as their normal payload is only up to 250kg. For towing the choice is only between MiR100 and MiR200. As the towing capacity of MiR100 is up to 300kg which does not leave a lot of room for any mistakes.

Table 4.13 Comparison of payloads of MiR AMRs [31]

	MiR100	**MiR200**	**MiR250**
Payload	100kg	200kg	250kg
Towing load	300kg	500kg	not possible

To ensure the MiR100 could transport the 280kg then the towing application specification needs to be analysed as well. The MiR100 uses MiR100 Hook for towing which has specification that the up to 300kg towing capability is only reached if there is no incline above 1% on the route, for bigger incline the capability drops to 200kg. [28] Relying on such floor evenness will not be reasonable and therefore, the MiR200 specification will be looked at. For MiR200 Hook the payload is said to be up to 500kg at less than 1% incline and up to 300kg with 5% incline. [32] This leaves a small buffer for weight and ensures the stability of the process. The MiR200 with the hook is shown on Figure 4.7.

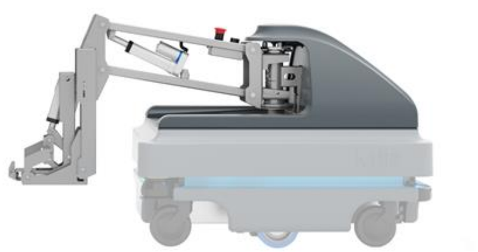

Figure 4.7 MiR200 with hook application [32]

Number of AMRs needed

The number of AMRs needed will be calculated based on the working portion calculation. If the efficiency of the AMR is less than 100% then one AMR should be enough, however if the efficiency needs to be more than 100% then more than one AMR is needed.

$$\frac{cycle\ time * cycles}{total\ time} = working\ portion \tag{4.1}$$

where the cycle time will be time spent moving from warehouse to production and back;

cycles are the total cycles gone through during the total time;

total time is the full time of the time being measured.

The cycle time needs to be calculated based on the maximum velocity of the MiR200 and the distance between warehouse and production to find the movement time and to that the loading/unloading time needs to be added. The movement time will be multiplied with 1,3 to add time of passing by obstacles.

$$cycle\ time = 1{,}3t_m + t_l \tag{4.2}$$

where t_m is the movement time;

t_l is the loading/unloading time.

The movement time will be found using the velocity equation:

$$t_m = \frac{s}{v} = \frac{2*150m}{1{,}1m/s} = \frac{300m}{1{,}1m/s} \approx 272{,}73s \tag{4.3}$$

where t_m is the time;

s is the distance;

v is the velocity.

The loading/unloading time will be assumed to be 2 minutes in total per cycle and therefore, the cycle time will be:

$$cycle\ time = 1{,}3 * t_m + t_l = 1{,}3 * 272{,}73 + 120 = 474{,}5(s) \approx 8min \tag{4.4}$$

The cycles will be calculated for both possible set ups separately and then the higher cycle count will be taken into consideration for the further calculations. The cycles need to be calculated in a way that the cycles needed for each line need to be calculated separately and then they will be added up. The cycle count per line needs to be rounded up to the next full number.

$$cycle = output/number\ of\ kits\ on\ trolley \tag{4.5}$$

For family A on automated line the cycles will be following:

$$cycles_A = \frac{188}{10} + \frac{96}{10} + \frac{80}{10} = 18{,}8 + 9{,}6 + 8 \approx 20 + 10 + 8 = 38 \tag{4.6}$$

For family B on automated line the cycles will be following:

$$cycles_B = \frac{160}{10} + \frac{96}{10} + \frac{80}{10} = 16 + 9{,}6 + 8 \approx 16 + 10 + 8 = 34 \tag{4.7}$$

The cycle count for family A trial is 38 and for family B it is 34, therefore, for the following calculations 38 cycles in considered.

$$working\ portion = \frac{8min * 38}{8h} = \frac{8min * 38}{(8*60)min} = 0{,}63 \sim 63\% \tag{4.8}$$

With the 63% working portion it can be said that one AMR is enough to serve the sub-assembly process. This leaves time for the AMR to be charged with minor impact on the process if any. Furthermore, the idle time can also be used to serve other material replenishment around the factory if needed.

4.5 Analysis of As-Is vs To-Be

The improved process will be evaluated based on the KPIs selected and the success of the changes can be measured accordingly.

Firstly, the output versus effort analysis will be done. This analysis will also have the impact from replacing one of the manual lines with automated line, however, this analysis will give an overall view of the sub-assembly process efficiency. The data is gathered into Table 4.14 where is can be seen that with the upcoming automated main assembly line and the improvements made in the sub-assembly process the total output of the production will remain the same.

For the same output a lot of less resources are needed as the number of main assembly lines is reduced by one and number of workers needed for sub-assembly process is decreased from 5 to 1 (not counting transportation workers). The average worker efficiency has been increased from 20% to 85% while the total worked time of preparing 350 sub-assemblies for production was decreased from almost 10 hours to less than 7.

Table 4.14 As-is and to-be sub-assembly process flow comparison

	As-Is	To-Be
Total output	352	350
Number of main assembly lines	4	3
Total number of workers	5	1
Total worked time (Kitting, SubAss)	09:52:13	06:50:07
Average working portion (Kitting, SubAss)	20,48%	85,44%

The improvements have helped to increase the workers efficiency and reduce production cost with using less resources. Therefore, it is clear both production related KPIs have been improved.

The improvements were also done in transportation field where the automation rate of transportation was increased from 0% to 100% with taking AMRs into use. In the current flow there is need for one transport worker who will take in total almost 7 hours to deliver all the frames from warehouse to production. In the improved solution one AMR needs to be used which total needed working time is a bit more than 5 hours. The exact data can be seen in Table 4.15. For transportation methods the working portion is only important to see ow much time of the resource is used for servicing sub-assembly process as all the transportation resources are shared with other material replenishment processes.

Table 4.15 Comparison between transportation methods as-is and to-be

	As-Is	To-Be
	Manual	**AMR**
Total deliveries	40	38
Total worked time	06:32:40	05:04:00
Working portion	82,00%	63,00%
Automation rate	0,00%	100,00%

The new process chart for sub-assembly process can be seen on Figure 4.8. The kitting step has been eliminated and the sub-assembly is done before transportation. This also shows how the excessive waiting and moving parts waste elimination was done during the improvement activities.

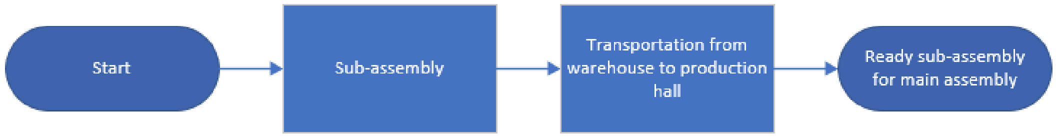

Figure 4.8 To-be sub-assembly process

5 IMPLEMENTATION PLAN

The implementation of these changes will be done gradually after the automated assembly line and packing line have been implemented. This is as the reasonability of kitting the carriers and frames together in the warehouse is only achieved when the carriers are already located in the warehouse. However, in the current production setup the carriers are released in the production hall. Therefore, implementing the full set of improvements before packing line installation will result in wasteful double transportation of the carriers.

The implementation of these improvements will be made in increments. The first step is to replace manual transport with AMRs as this step takes the longest and does not need alignment of processes. The implementation of AMRs will be iterative and lasts throughout the implementation. The fleet management set-up and integration into existing systems will be a continuous task. As the next step the RFID writing software capabilities will be added to the sub-assembly station of the automated main assembly and the software will be tested.

During the same time period, alignment discussions can be held to merge the kitting and sub-assembly stations into one and locate the workstation in warehouse. After that the implementation of merging the sub-assembly stations can begin. The full implementation plan can be seen in Gantt chart format in APPENDIX 4.

After the improvements have been implemented, the new goals should be considered such as loading the kits to main assembly automatically without usage of lifts, improving the cycle time of the sub-assembly station and automating the signalling from production to warehouse when the kits are running out.

6 ECONOMIC FEASIBILITY

To evaluate the return on investment (ROI) of the improvements recommended in this paper, the as-is and to-be process expenditures are compared and the ROI will be found.

Firstly, the variables are gathered, after that the costs for both process options are calculated and then the comparison will be made.

The variables include the cost of a worker which has been taken from the Statistics Estonia salary comparison data for production support worker [33], the number of workers is the number of needed workers per shift for the sub-assembly process and the total number of workers over shifts. As the factory is working 24/7 in 2 shifts then there needs to be 4 shifts workers to have continuous production running without going over workhour limit. The variable values are brought out in Table 6.1.

Table 6.1 The variables for economic calculations

	Value	**Relevant model**
Cost of a worker	€ 1 150,00	
Number of workers per shift	5	As-Is
Number of workers per shift	1	To-Be
Number of shifts	4	
Total number of workers	20	As-Is
Total number of workers	4	To-Be

The running costs and initial investment of the to-be process will be calculated and then the analysis will be done over monthly periods to find the ROI. The re-occurring costs for both processes can be seen in Table 6.2.

Table 6.2 Re-occurring costs

Re-occurring cost for as-is	
Monthly workers cost	€ 23 000,00
Re-occurring cost for to-be	
Monthly workers cost	€ 4 600,00

The initial investment for to-be process and the maintenance costs needed for the AMR will be shown in Table 6.3. The cost of the AMR is approximation based on previous experience of the author. The maintenance cost includes the salary of the technical support of the AMR as well as the normal maintenance of the RFID writing process including hardware and software. The set-up costs for AMR and project management costs are calculated based on the implementation plan and the basis of the cost was the

3 months work of implementation with average 3000 euros of cost for salaries and administration. There is added programming costs for the AMR fleet management as well as for the integration of AMRs in the existing replenishment system. The RFID writing hardware includes the RFID writer, barcode scanner and the PC with screen. The new trolleys cost is an estimation for the trolleys design and production.

Table 6.3 Initial investment

	Cost
AMR	€ 35 000,00
Maintenance cost (monthly)	€ 3 000,00
AMR set up costs	€ 3 000,00
Programming costs	€ 30 000,00
Project management	€ 9 000,00
RFID writing hardware	€ 2 000,00
New trolleys	€ 12 000,00

The full analysis of the ROI can be seen in APPENDIX 5 and the chart of cumulative costs per months can be seen in Figure 6.1; the ROI will be reached in 6 months. This ROI was expected and can be considered as a successful result and therefore, it can be said the improvements are economically feasible.

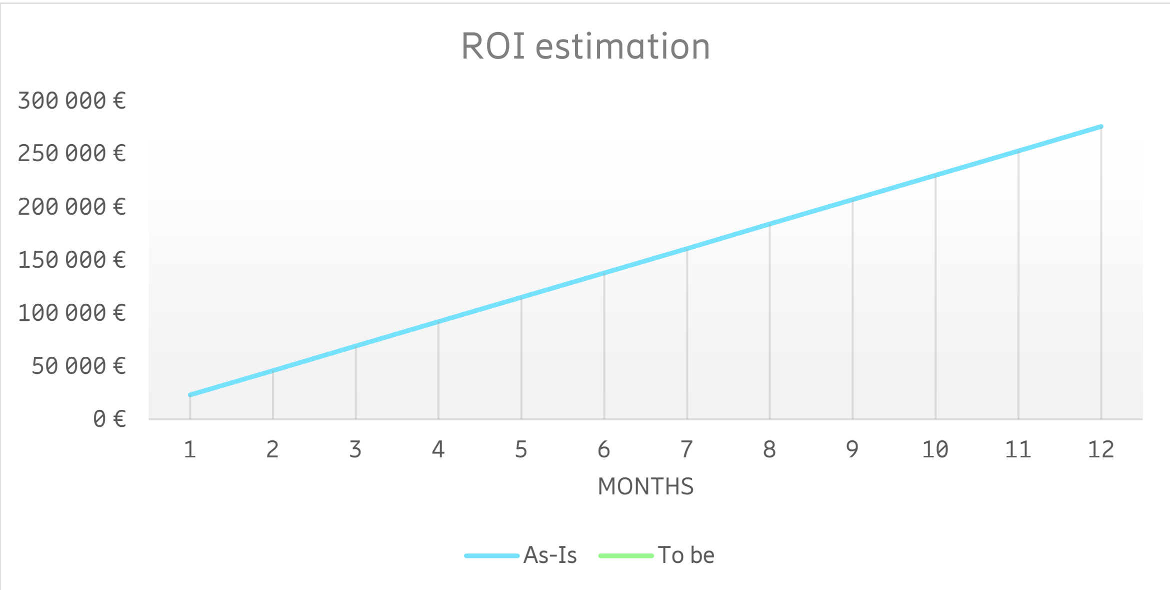

Figure 6.1 ROI estimation chart

SUMMARY

The main aim of this thesis was to analyse and find ways to optimise the sub-assembly process in radio production in Ericsson Supply Site Tallinn according to eight wastes theory and local key performance indicators. Thanks to the improvements proposed many wastes were eliminated and KPIs were improved.

The thesis served as a proof of concept for the company and therefore, can be considered as a success as the main bottlenecks and inefficiencies were identified and it was proven that they can be eliminated with implementable improvements. The as-is and to-be processes were simulated and according to those the increase of efficiency will be over 60% thanks to the increase of working portion of the sub-assembly station. Thanks to the simulation it was also proved that the current 4 sub-assembly stations are under-utilised and therefore, merging them together will increase their efficiency as well as reduces the cost of workers. Additionally, the sub-assembly process was brought to warehouse to decrease excessive movement of carriers.

For the transportation between warehouse and sub-assembly station simulation showed that less than one worker is full-time needed to replenish the material to the sub-assembly station; however, the transportation would increase twice with the upcoming packing line. As according to eight wastes theory excessive transportation is considered a waste and the company's goal is to move towards automation in all fields – including transportation, then the analysis for replacing manual transportation with other means was conducted. The proposed way forward was to implement AMRs and specifically use MiR200 robot with added hook for the job.

Thanks to the improvements all three KPIs analysed were improved: workers utilisation increased by 60%, the production cost reduced by cutting the worker count from 5 to 1, and the rate of automated transport increased for this process from 0 to 100%. Furthermore, three wastes were identified and eliminated: waiting by higher utilisation, movement by eliminating the unnecessary movement of carriers, and transport by automating it.

The results of this thesis will be analysed in greater detailed with more elaborative data and be based on the implementation that will be carried out in the company.

In conclusion, the thesis has had positive impact on the company and has provided valuable insight by simulating the future view on sub-assembly process in times when the factory is in the midst of big changes of automation as well as providing insightful improvements to be implemented in the future.

KOKKUVÕTE

Töö peamine eesmärk oli analüüsida ja leida optimeerimisvõimalusi raadiotootmise alamkoostu protsessile Ericsson Supply Site Tallinnas kaheksa raiskamise teooria ning tulemuslikkuse võtmenäitajate abiga. Tänu parendusettepanekutele vähendati raiskamist mitmes valdkonnas ning võtmenäitajad paranesid.

Antud töö oli ettevõtte jaoks vajalik tõestus, et arendus on selles vallas vajalik ning seetõttu võib väita, et töö teenis oma eesmärki edukalt. Töö käigus tulid välja pudelikaelad ja ebaefektiivsed tegevused, mille eemaldamiseks pakuti juurutatavaid lahendusi. Hetkeolukorra ning tuleviku väljavaate simulatsioonide võrdluse põhjal saab väita, et efektiivsuse kasv oli 60% tänu alamkoostu tööjaama tööaja efektiivsemale kasutusele. Tänu simulatsioonile tõestati, et hetkel kasutusel olevad 4 alam-koostu tööjaama on vähekasutatud ning nende liitmisel tõuseb nii tööjaama efektiivsus kui ka vähendab see tööjõukulusid. Alam-koostu protsess liigutati laoalale, et vähendada toote tööaluse ülemäärast liigutamist.

Lao ja tootmisala vahelise transpordi simulatsioon tõi välja, et vähem kui üks transporttööline on vajalik alam-koostu tööjaama vajalike materjalide vedamiseks. Teisalt kahekordistuks transpordimäär automaatse pakkeliini tuleku ja toote tööaluste vedamisega laost tootmisalale. Kaheksa raiskamise teooria kohaselt on ülemäärane transport raiskamine ja ettevõtte üheks eesmärgiks on automatiseerimine igas valdkonnas, seetõttu analüüsiti manuaalse transpordi asendamist automaatsega. Valituks osutus isesõitev mobiilne robot MiR200, millele on lisatud konks käru vedamiseks.

Tänu parandusettepanekutele parendati kõiki kolme tulemuslikkuse võtmenäitajat: töötajate efektiivsus tõusis 60%, tootmiskulud vähenesid tänus tööjõu vähenemisega 5-lt 1-le inimesele ning transpordi automatiseerimine tõusis 100%-ni. Lisaks sellele avastati kolm raiskamist, mis elimineeriti: ooteaega vähendati tänu kõrgemale tööajale, liigne liigutamine vähenes tänu protsessi lattu viimisega ning liigne transport vähenes tänu automatiseerimisele.

Töö tulemusi analüüsitakse ettevõttesiseselt edasi ning detailsemate andmete põhjal juurutatakse muudatused tootmises.

Antud tööl oli positiivne mõju ettevõttele, pakkudes vaadet alamkoostu protsessi tulevikku ja selle võimalusi aegadel, kus tehases toimuvad suured muudatused.

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APPENDICES

```
WarehouseA1.exitlocked:=false
ProBufferA1.entrancelocked:=false
WarehouseA2.exitlocked:=false
ProBufferA2.entrancelocked:=false
--WarehouseB1.exitlocked:=false
--ProBufferB1.entrancelocked:=false
WarehouseB2.exitlocked:=false
ProBufferB2.entrancelocked:=false

--The following part is added during the improvements

-- changing the automated line cycle time based on the product family
if pro = 1
    -- 1 is product A and 2 is product B
    MainAssAuto.ProcTime := 2:30
    --MainAss2.ProcTime := 6:00
else
    MainAssAuto.ProcTime := 3:00
    --MainAss2.ProcTime := 5:00
end

-- changing the buffer capacities according to the trolley capacity
WarehouseA1.Capacity := i
WarehouseA2.Capacity := i
--WarehouseB1.Capacity := i
WarehouseB2.Capacity := i
ProBufferA1.Capacity := i
ProBufferA2.Capacity := i
--ProBufferB1.Capacity := i
ProBufferB2.Capacity := i

-- changing the trasnporter worker capacity according to trolley capacity
.UserObjects.TransporterLine.Zdim := i
```

APPENDIX 2 Results from simulation runs with varying trolley capacity

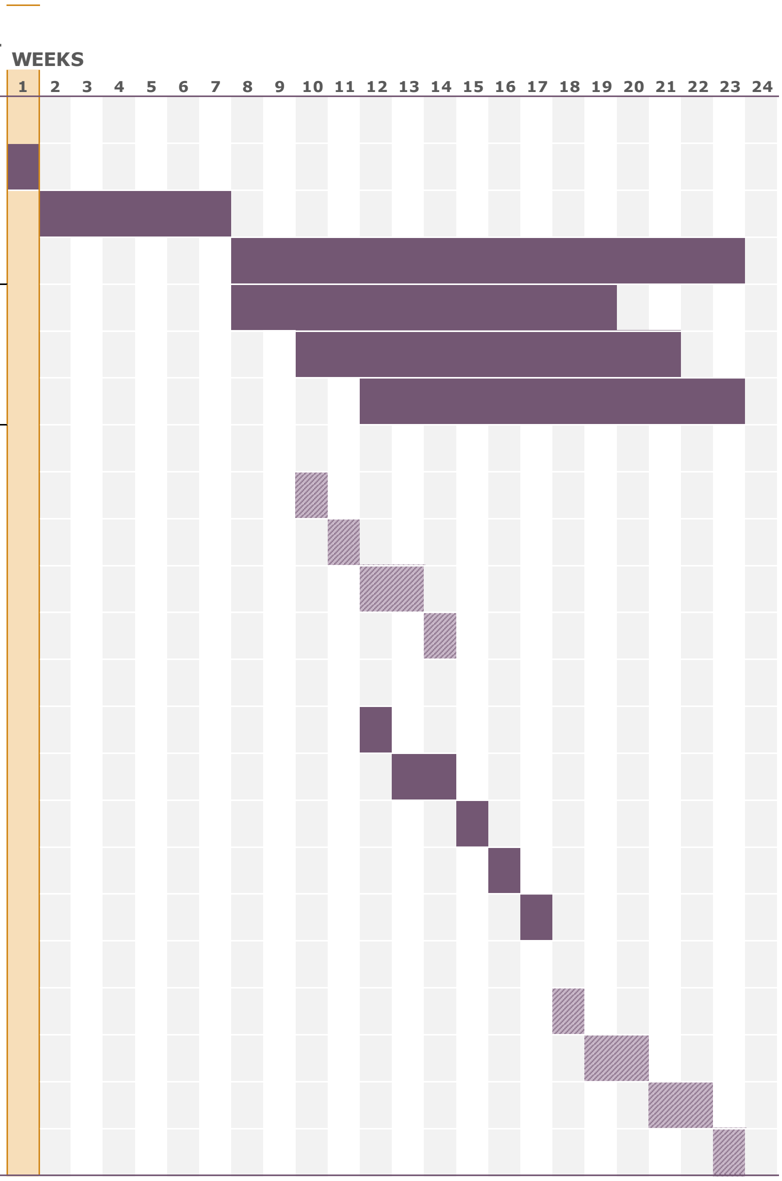
	Qty on trolley		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Automated family A	SubAss		60,08%	83,13%	87,80%	87,22%	87,26%	87,82%	87,82%	87,26%	88,25%	88,78%	89,54%	90,71%	90,75%	92,24%	92,07%	94,04%	95,51%	94,21%	94,38%	95,08%
	MainAss Auto	AutomA	43,44%	86,67%	95,00%	95,55%	95,89%	96,86%	96,86%	97,05%	97,64%	97,75%	97,61%	98,52%	98,71%	97,87%	97,70%	97,35%	96,61%	97,14%	96,93%	96,54%
	MainAss 1	ManA	87,50%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	MainAss 3	ManB	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	Output	AutoA	83	166	183	184	184	186	186	186	187	188	188	189	189	188	187	187	185	186	186	185
		ManA	84	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
		ManB	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Automated family B	SubAss		60,08%	81,67%	81,88%	81,67%	81,42%	81,63%	81,03%	81,67%	81,93%	82,09%	82,40%	84,39%	83,58%	86,12%	86,20%	87,07%	88,03%	87,65%	87,06%	88,03%
	MainAss Auto	AutomB	52,08%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	99,63%	99,19%	99,19%	99,60%	99,60%	99,60%	99,60%
	MainAss 1	ManA	87,50%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	MainAss 3	ManB	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	Output	AutoB	83	160	160	160	160	160	160	160	160	160	160	160	160	159	159	158	159	159	159	159
		ManA	84	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
		ManB	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80

APPENDIX 3 Comparison of different transport methods

	Manual transport	Conveyor		Robots	
		floor	ceiling	AGV	AMR
Speed	0,9m/s	0,2m/s [24]	0,2m/s [24]	0,55m/s [25]	2m/s [26]
Time per 150m	167s	750s	750s	273s	75s
Payload	200kg	100kg [24]	100kg [24]	140kg (towing 500kg) [25]	100kg (towing 300kg) [26]
Set up price	N/A	400 000 EUR	435 000 EUR	30 000 EUR/ppc	35 000 EUR/ppc
Set up needs	N/A	Fire safety modules put in place where the conveyor must go through wall.	Additional lifts need to be added to lift products and fire safety modules put in place where the conveyor must go through wall.	Tracks need to be put on route.	Fleet management system needs to be set up if more than 2 AMRs are in use
Maintenance cost	1150 EUR/per month [33]	3000 EUR/per month	3000 EUR/per month	500 EUR/per month	3000 EUR/per month
Flexibility	Can move everywhere	Fixed to the route chosen	Fixed to the route chosen	Route can be changed with changing the tracks on floor	Re-programmable
Safety	The safety of the worker needs to be considered and the work-force law needs to be respected. Furthermore, the trolley needs to fulfil safety requirements.	The conveyor must be protected from workers accidentally putting their fingers between moving parts.	The conveyor needs to be protected from the sides to ensure the products do not fall.	The route must not be on the walking path of the people.	Needs to be programmed to not hit into other equipment.
Factory specific comments	No changes would be need for having manual transportation; however, new trolley for the transportation might need to be considered.	Both conveyor options are fixed which in case of the occurrence changes will be an hinderance for the factory floor management. Furthermore, the fire safety doors on the route mean the conveyor must take these into account and special fire safety modules need to be placed. The route is not straight and has many intersections with other routes in factory which means the floor conveyor would be considered as an obstacle for other transportation routes.		The route where the AGV would move, is the same that is used for people and in warehouse the route is crossed with forklift route. Therefore, the tracks can be broken easily by wear of other transporters.	The factory is already using AMRs for other transportation routes and therefore, adding extra AMRs would not be a problem.

APPENDIX 4 Gantt chart of implementation

	ACTIVITY	PLAN START	PLAN DURATION
	AMRs implementation		
	Purchase AMR with hook	1	1
	AMR LT	2	6
	Fleet management	8	16
Iterative	Teach routes (4 routes)	8	12
Iterative	Testing	10	12
Iterative	AMR running	12	12
	Setting up RFID writing capability		
	Setting up the hardware	10	1
	Installing the software	11	1
	Testing the software	12	2
	Software working	14	1
	Alignment of processes		
	Handshake with management	12	1
	Process creation	13	2
	Process mapping	15	1
	Work instructions creation	16	1
	Processes aligned	17	1
	Merging the workstations		
	Setting up the workstation in WH	18	1
	Training employees	19	2
	Testing the process	21	2
	Process is implemented	23	1



APPENDIX 5 Full Return on Investment calculation

Project timeline													
Timeline	**Year**	1											
	Month	1	2	3	4	5	6	7	8	9	10	11	12
As-is	**RE-OCCURRING COSTS**												
	Worker's salary	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €
	Total costs	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €	23 000 €
	Cumulative costs	23 000 €	46 000 €	69 000 €	92 000 €	115 000 €	138 000 €	161 000 €	184 000 €	207 000 €	230 000 €	253 000 €	276 000 €
To-be	**INVESTMENT**												
	AMR	35 000 €											
	Maintenance	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €	3 000 €
	AMR set up costs	3 000 €											
	Project management	9 000 €											
	RFID writing hardware	2 000 €											
	New trolleys	12 000 €											
	Programming costs	30 000 €											
	RE-OCCURRING COSTS												
	Worker's salary	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €	4 600 €
	Total costs	98 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €	7 600 €
	Cumulative costs	98 600 €	106 200 €	113 800 €	121 400 €	129 000 €	136 600 €	144 200 €	151 800 €	159 400 €	167 000 €	174 600 €	182 200 €
Calculations	**Monthly benefits**	-75 600 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €	15 400 €
	Yearly benefits	93 800 €											
	Return on Investment	-75 600 €	-60 200 €	-44 800 €	-29 400 €	-14 000 €	1 400 €	16 800 €	32 200 €	47 600 €	63 000 €	78 400 €	93 800 €
	Months for RoI	6											

GRAPHICAL MATERIAL