Improving the packaging of Crosslaminated timber

A master thesis that examines the environment and methods at Martinsons Såg, Bygdsiljum

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Industrial Design Engineering, master's level
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Luleå University of Technology
Department of Business Administration, Technology and Social Sciences

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2017

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CIVILINGENJÖR I TEKNISK DESIGN
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Luleå 18th of April 2018

Viktor Berglund

Abstract

This thesis is the final assignment for the program master of science in Industrial Design Engineering at luleå university of technology. The timespan is September of 2017 and early January 2018 and is equivalent to 30 high school credits. The work was performed at Martinsons Såg in Bygdsiljum, Sweden. Martinsons is Sweden's largest producer of cross-laminated timber, crosslam. The staff is divided into two shifts with nine workers each. The production consists of three sections, gluing, CNC and shipping. The factory was expanded in early 2017 but did not achieve planned output. The last section, the shipping, is a bottleneck. The object of this thesis is to find a layout that solves the bottleneck and improve the working conditions in the shipping, and the pace of the system should be determined by the first process, the pressing.

The production starts with the planks. Planks are cut to the right dimensions by a saw and placed in layers. Glue is then applied, and more layers are placed and moved to a press while the glue dries. It results in panels. The maximum size of the panels is 16x3 m. A CNC saw cuts the panels to litteras, custom order parts used to build everything from houses to public areas. The workers pack the littera manually. When the litteras are packed, the packages are loaded on trucks for delivery to the customers.

The theoretical background of this thesis consists of three major subjects: industrial design engineering, ergonomic and lean production, with a focus on waste reduction. To understand the system the flows and working procedures were documented with observations, interviews, a survey and some filming. An OWAS were used to observed the ergonomic risks and analyse how they can be avoided. Later in the project were a brainstorming session and workshop used to generate concepts to solve the problems. The concepts were evaluated with a value matrix.

The results from the examination of the system showed that the real bottleneck in the system was the crane. It was slow and is also used in the waste flows. Two packaging stations for the litteras cannot be used because of the flow of the sawdust, lowering the capacity and flexibility in the packaging. Summarised, the crane could not deal with the demands from the rest of the system. The ergonomic problems consisted of bent and twisted backs while the workers pack the littera.

This thesis proposes an investment plan to solve these problems. It consists of two investments that expand the building and expand conveyors, thus removing much of the lifting much lifting with the crane. The waste and littera flows are separated to allow the crane to focus on the main flow of littera

Two new kinds of packaging stations are implemented to help with the packaging: standard stations that pack the littera on lifts and wall packaging stations that packs littera meant for walls that have many weaknesses. The standard stations consist of scissor lift tables that help reduce the time spent with a bent back while packaging. The temperature is maintained at comfortable levels with an airlock to the outside.

KEYWORDS: Flow optimisation, Lean, OWAS, Working conditions, Throughput improvement, Waste flows

Sammanfattning

Detta examensarbete är den slutliga uppgiften för utbildningen Civilingenjör i Teknisk Design: Produktionsutveckling vid Luleå tekniska universitet. Tidsperioden för arbetet är september 2017 tills januari 2018 och representerar 30 HP. Arbetet har utförts på Martinson Såg i Bygdsiljum, Sverige. Martinsons är Sveriges största producent av korslagda limträskivor, KL-trä. Fabriken som producerar KL-trä består av 2 skift med 9 arbetare vardera. Arbetarna är vidare uppdelade i tre sektioner; limning, CNC och utlastning. Systemet expanderades i början av 2017, men har inte kunnat producera vid de kapaciteter som de planerat. Orsaken är att den sista delen, utlastning, är en flaskhals. Syftet med detta examensarbete är att hitta en lösning som ökar produktionen och förbättra arbetsförhållandena vid utmatning. Systemets takt ska kunna bestämmas av den första maskinen, pressen.

Produktionen börjar med plankorna som kapas till rätt mått och placeras i lager. Lim appliceras mellan lagren. Där efter flyttas skivan till en press som håller tryck på skivan medan limmet torkar och bildar upp till 16 * 3 m stora block. Blocken kapas sedan till littera, kundanpassade skivor som används till att bygga allt från hus till offentliga miljöer. Skivorna paketeras manuellt innan de skickar till kund.

Den teoretiska bakgrunden till detta examensarbete består av tre delar: en beskrivning av vad Teknisk Design är, vad ergonomi är och orsaken till MSD och Lean-produktion, med fokus på minskning av avfall. Med observationer, intervjuer, en enkät och en filmstudie dokumenterades flöden och arbetsrutiner för att förstå vad som händer i fabriken. Med en OWAS observerade och analyserade de ergonomiska riskerna för att undvika dem. Med en brainstorming och en workshop genererades sex koncept som värderades med en värdematis.

Resultaten visade att traversen i systemet var den verkliga flaskhalsen. Den var långsam och användes även till sidoflöden. Sågspånsflödet ledde till att två arbetsstationer inte kunde användas. Detta orsakade fler problem genom att Flexibiliteten vid paketering minskades. Sammanfattat så kunde kranen inte hantera kunde inte hantera kraven som ställdes från systemet. De ergonomiska problemen bestod av böjd och vridna ryggar då arbetarna paketerade litterorna.

För att lösa problemen föreslås en investeringsplan. Den består av två investeringar som expanderar byggnaden och installerar fler transportband som minskar kraven på traversen. Sidoflödena separeras från litterorna, så transportörerna kan fokusera på huvudflödet. Två nya typer av stationer föreslås för att hjälpa till med packningen: normala stationer packar med hjälp av saxliftar och för att kunna justare arbetshöjden. Medans litteror som ska används till väggar paketeras stående. De resulterar även i färre ryggböjningar under paketeringen och säkrare hantering av paketen. Temperaturen föreslås hållas på bekväma nivåer med en luftsluss till utsidan.

NYCKELORD: Flödesoptimering, LEAN, OWAS, Arbetsförhållanden, Sidoflöden, Genomflöde

Content

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List of Technical terms

Bits	Larger portions of the panel that is cut and removed because it has a shape that is impractical to use.
Conveyors	Rollers that are used to transport the panels and litteras in the factory
Crosslam	A Glulam product that consists of 3 to 7 layers of crossed planks. It is used to build sustainable buildings
Cut-outs	A part cut to make space for a window or door in a littera. Can be sold separately
Littera	A cut part from the panel. The littera is the part that the customer receives
Panels	A pressed board of crosslam, up to 16*3 meters. Is cut to Littera
Remains	Thin sheets of wood that are not cut completely in the CNC.
Waste	Any activity that does not add value to the customer and that could have been avoided.

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1 Introduction

This master thesis is conducted at Martinsons Såg in Bygdsiljum, Sweden, to enhance the production of cross-laminated timber. To achieve this, the flow, layout and routines in the later part of the process must be improved. This thesis is the final assignment of the master programme in industrial design engineering at Luleå University of Technology. The time span is September 2017 to January 2018.

1.1 Background

The world is facing many problems. One of them is that our society puts a strain on earth's supply of non-renewable material, such as steel, and with the increasing CO_2 emissions, the climate of the world is changing (Barron & Washington, 1985). The world must reduce its carbon footprint, or we will face the consequences. One way to reduce the CO_2 emissions is to use more renewable wood in buildings, for example glulam. Glulam has strength equal to steel, is renewable, and stores CO_2 during its entire lifetime. One company that produces glulam is Martinsons in northern Sweden. They also produce a more advanced form of glulam called cross-laminated timber, henceforward crosslam. Crosslam is an improvement of glulam. For example, it is more moisture resilient.

Martinsons has produced crosslam since 2003 and expanded the sawmill in January 2017 to have a specialised factory to produce crosslam. They are now able to make panels up to 3 m wide in a mostly automatic factory. With the expansion, the capacity has increased to 22000m^3/year.

However, the expansion resulted in problems, especially after the press machine. Uneven flows, bad work environment, and an abundance of "unnecessary" tasks are some examples. These problems result in difficulties for Martinsons to achieve their planned volumes due to a bottleneck in the shipping. The situation needs to be improved.

1.2 Objective and aims

The aim and object of this project are:

This project has the object to improve the shipping to ensure that the press decides the pace, with the aim to present a new layout and routines in the shipping area.

To work efficiently with the objective a primary question has been formed:

What can Martinsons do to improve their throughput in the shipping?

The primary question is further divided into two sub-questions:

- *How can the flows in the machines and shipping be improved?*
- *What are the problems in the work environment and how can they be addressed?*

1.3 Stakeholders

For this project, two stakeholders were identified; Martinsons and Luleå University of Technology, henceforward called LTU.

Martinsons has the role of the employer and the customer and is the primary stakeholder. The workers are the users of the solution. Any changes will affect their routines. During the project, they will be disturbed in their work by visits and questions. The board expects a solution that solves the problems. Eventually, Martinsons will invest in the proposed solution. Therefore, the solution must solve and improve the current system. They are required to answer questions and supply the information and data needed to solve the problems. Jon Martinsons, the man responsible for the production of crosslam, represents them as the contact at Martinsons.

LTU is an external stakeholder in this project. They expect that the result will have a certain quality, as they will publish it. They demand that the solution must be of a certain quality and based on scientific knowledge. Otherwise, the reputation of would be damaged, and Martinsons would lose time and money invested in a faulty solution. Magnus Stenberg, a lecturer at LTU, represents them as the supervisor for the project.

1.4 Project scope

This project will focus on the flows and work conditions in the parts after the CNC and the shipping, as this is where the major problems are. The gluing is assumed to meet current demands. Martinsons is more interested in the payback time of the solution than the cost. The actual implementation of the solution is outside the scope of this project. Martinsons is planning to change both the product mix and improve the machines to lower wasted time. This project assumed that there would be no change compared to the current situation.

The time scope of this project is early September 2017 to the end of January 2018. One person works full time, 40 h/week, for a total of 800 hours in this project, equivalent to 30 credits at a Swedish University.

1.5 Thesis outline

This thesis consists of 11 chapters. Chapter 1 presents the background, objective stakeholders and scope of the project. Chapter 2, Context, describes the current situation in the production. It includes a description of crosslam, the current layout and flows, the environment and the future of the factory. In chapter 3, The theoretical framework is presented. The framework consists of Industrial design engineering, Flows, efficiency, physical environment, and the psychosocial environment. Chapter 4, Methods, describes the methods used in the project.

Chapter 5 describes the current situation at the company. There are the flows and working conditions described, and the problems summarised. The major problems are then further analysed in Chapter 6. Chapter 7 describes the specification and grades the important aspects of it. Chapter 8 presents several ideas for how the situation can be improved, including new layouts and changes in details. In chapter 9 the concepts are graded and summarised in a final solution with a proposed implementation. Chapter 10 describes the solutions in details. Lastly, chapter 11 presents the conclusion of the thesis with a discussion.

2 Context

Martinsons Såg in Bygdsiljum is a part of the Martinsons group. They are a company that "transforms the northern Swedish forest into innovative components and ready-to-use solutions". (Martinsons, n.d.-a) The Martinsons group main office is located in Bygdsiljum and consists of five different companies, each of which specialises in different areas, as production, sales, and building. The Martinsons group is Sweden's largest producer of glulam and has a leading role in the construction of wooden bridges and building systems with wooden frames in Scandinavia. Since this project only affects Martinsons' sawmill in Bygdsiljum, the name "Martinsons" is used synonymously with Martinsons Såg in Bygdsiljum, unless stated otherwise.

2.1 Cross-laminated timber

Crosslam is an improvement of conventional glulam and consists of several layers of planks that are glued together to form a massive wooden panel, see Figure 1. Each layer is rotated 90° compared to the previous layer crossing each other. Crosslam has many advantages that make it an excellent choice for buildings. For example, it is easy to handle and has a high flame resistance.

Martinsons produces panels with 3, 5 or 7 layers. The maximum dimensions of the panels are 16x3m, with 21 different thicknesses. The panels can have one of three finishes classes: Construction, Industrial and Visible. The most common class is construction and is the roughest. It can have colour differences between the planks, knotholes and many other flaws. Visible is the finest with greater demands on the appearance of the planks. Visible panels are sanded to achieve a finer surface. Industrial is between construction and visible and can have some flaws.

Smaller elements called "littera" are cut from the panels. Rectangular littera are the most common, but triangular ones can also be produced, for instance, to be used in gables, see Figure 1. One panel can be used for 1-20 litteras, depending on the sizes. Some littera has holes for windows doors and other details if the customer demands it. The litters are used in everything from inner and outer walls to public spaces like hotels and offices

When a customer wants to place an order of crosslam, the customer contacts Martinsons Byggsystem. The customer and a seller at Martinsons Byggsystem create a blueprint for the project together. A production order containing the required litteras is sent to the CAD-drawer in the factory. Three documents are sent to different parts of the production. The inspection receives a request for material to the panel. The CNC receives a cad file on how to cut it and the shipping gets a packaging list. Every littera is custom-made for a specific order. A production and information chart is presented in Figure 2.

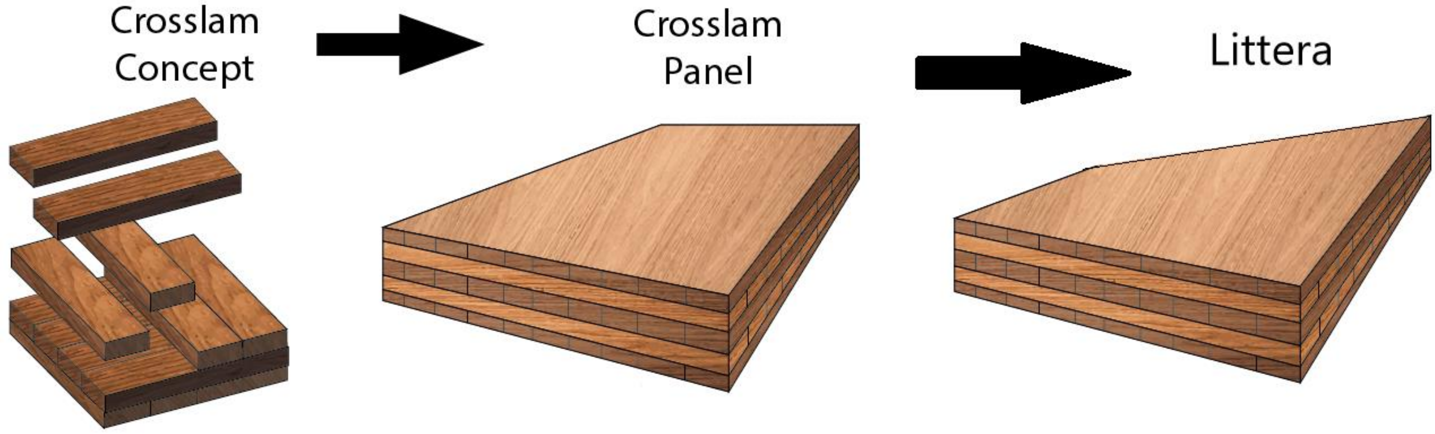

Figure 1: The concept of Crosslam

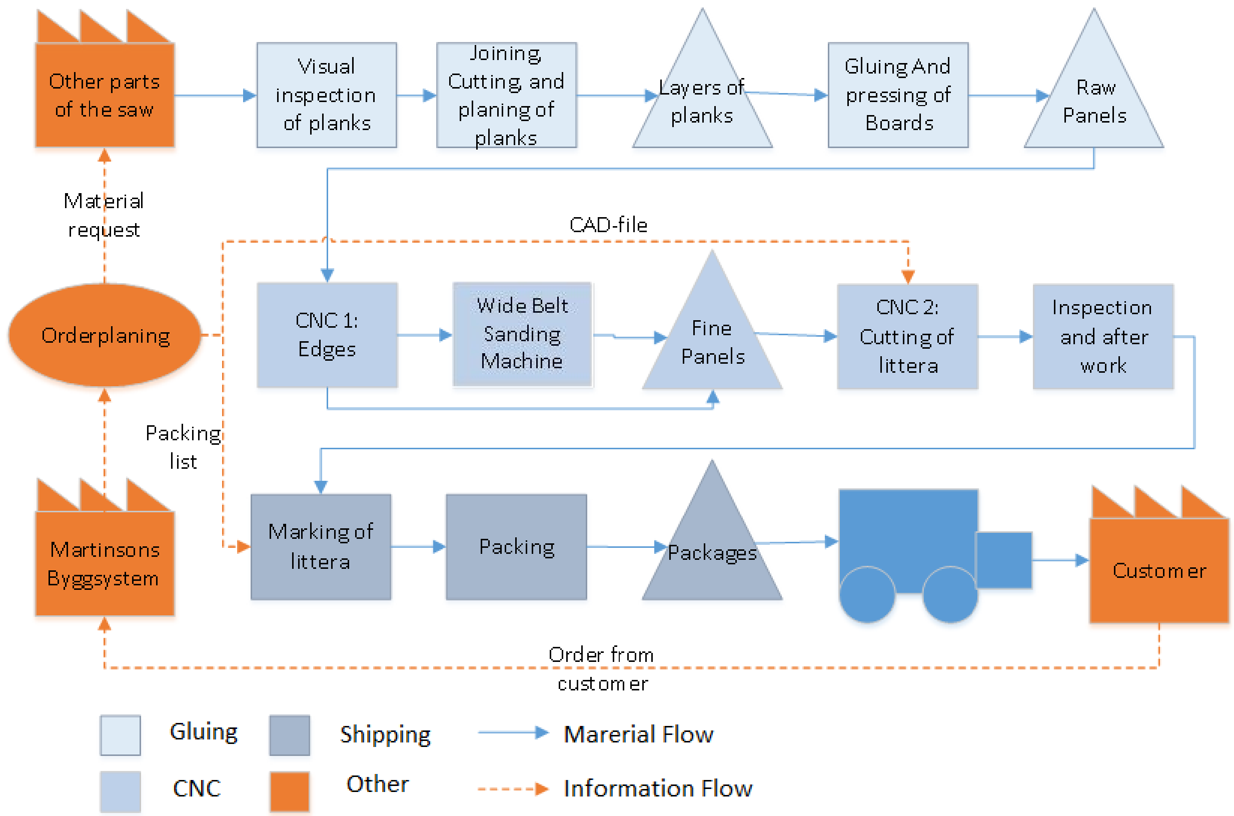

Figure 2: Production Chart

2.1.1 Crosslam future of in Sweden

Currently, Martinsons has the only factory that produces crosslam in Sweden. The current demand for crosslam in Sweden is twice Martinson's current capacity. Martinsons has no plans to increase the production volume, despite the large demand for crosslam.

Two competing companies are planning on establishing more factories in Sweden. Jon Martinson claims that Martinsons is not worried about the new competition, as it will increase the demand for crosslam.

2.2 The factory and production

The process consists of three parts; the gluing, CNC, and shipping. It starts with planks which are joined and cut to the right lengths and dimensions. The cut planks are then placed in layers and glued. When all layers have been placed, they are moved to the timber presser by chain conveyors. The panel is pressed for 30 minutes for the glue to dry. The chain conveyors are used throughout the factory and are henceforward called conveyor.

After the press has finished, the edges are rough and need cutting. This occurs at the first CNC. If any panel needs a finer finish, as for the class visible, the conveyor transports the panels to a Wide-belt sander, henceforward sander. From the panels, litteras are cut in the second CNC. A so-called post-CNC station then checks the dimension and makes adjustments if required. After that, the bits cut for windows and doors, known as cut-outs, are recovered to be sold separately. The workers call this station "the plunder station" as they are plundering the panel for useful parts. This report uses that name henceforward. The CNC area ends with the plunder station. After the cutting, the litteras are moved to the shipping and packed manually. The crane lifts the packages to a trolley that moves the packages outside before they are loaded onto trucks for transport to customers.

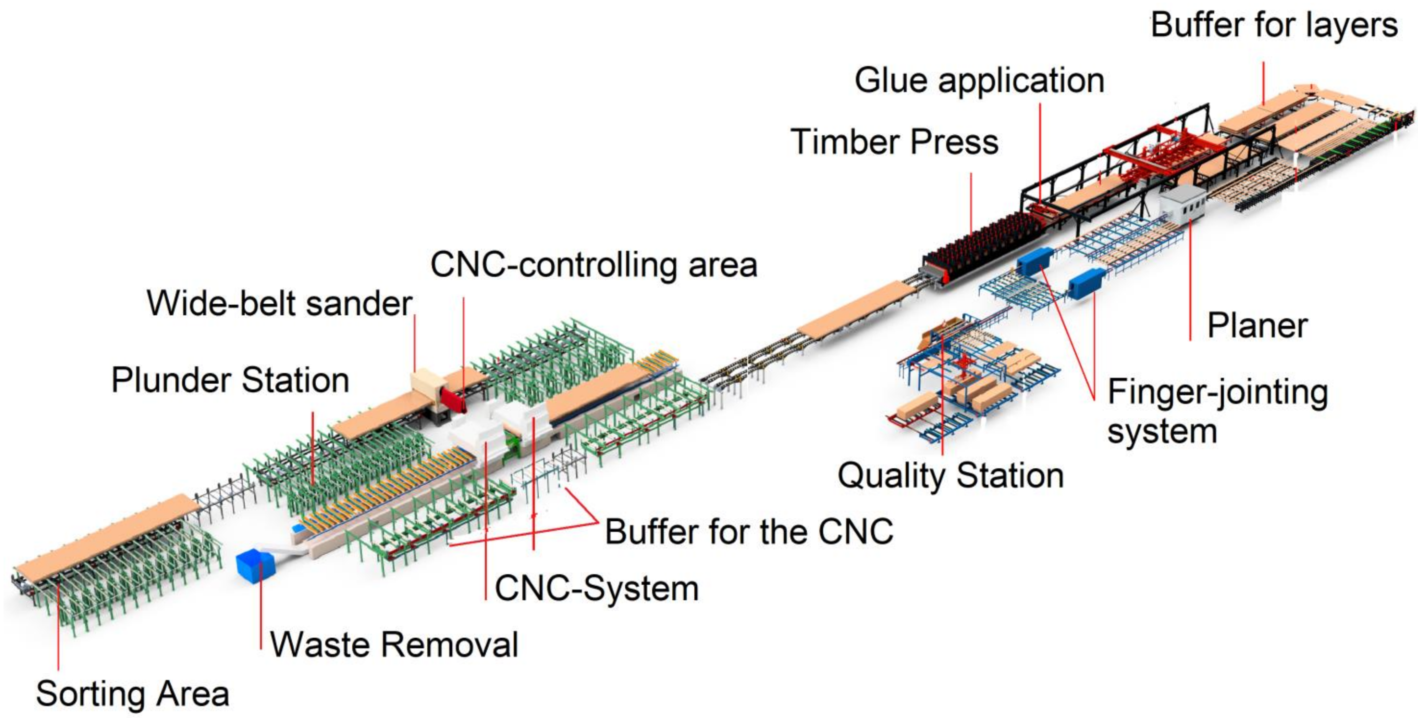

Figure 3: The 3D layout (Martinsons n.d. with slight modifications)

2.2.1 The layout and environment

The environment has two sections, the new part, with the CNC and shipping, and the old with the gluing and press. The old part was previously used to produce normal glulam, but it has been developed to produce crosslam instead. The machines and layout are presented in Figure 3.

In the old part, Martinsons used to make regular glulam, but have been changed to produce crosslam. The newer part was built in late 2016 and has more space compared the old part. The conveyor for the panels and litteras create a rectangle around the CNC-operating area.

The shipping starts with the sorting area, see Figure 4. The floor is raised 2.2 meters above the floor, to be in level with the conveyers and other machines. The floor is mostly empty with only a few tables to pack the littera on. On the other side of the packaging area, a trolley is used to move the packages outside. The shipping has two cranes; one is used to lift the littera to the floor, while the other crane is used to lift the packages on the trolley. The cranes are moving on the same track.

All the machines have barriers and gates to prevent accidents; the gates will stop the conveyors if opened. The exception is the plunder station and sorting area, where the gates are removed. The workers need to be closer to the panels during the plunder, compared to the gluing. The only part not fully automated is the shipping and plunder station. The newer section has bridges over the conveyors, for the workers to use, see Figure 5. All workers wear headsets with a radio for ear protection and communication, as loud noises are emitted from the machines. All workers and visitors wear a safety vest to increase visibility.

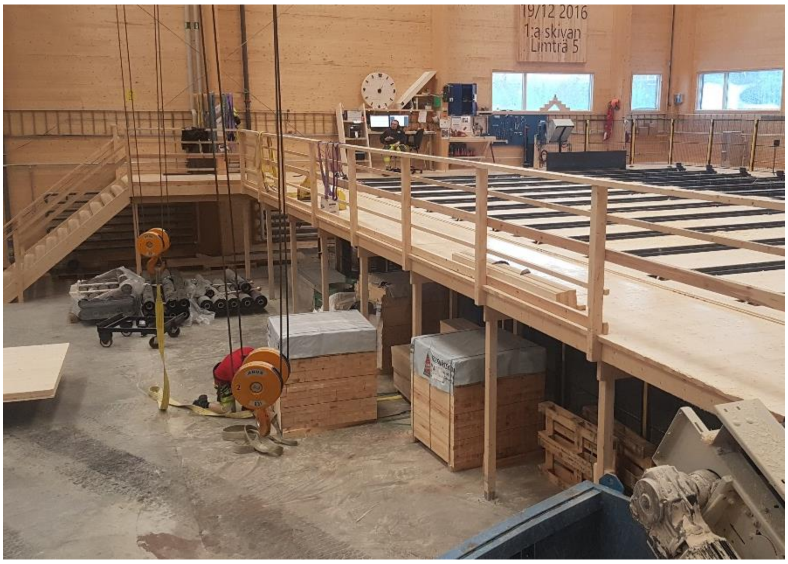

Figure 4: The difference in level in the shipping

2.2.2 Organisation

At the top of the organisation is the board of the Martinsons group. One board member is responsible for crosslam. This person has a smaller organisation that includes production leader for crosslam. At the beginning of each shift, a meeting is held where the workers are informed about the management and the current situation in the production is updated. The Martinsons group handles all financial aspects of the factory and provide the factory with material to use.

2.2.3 Previous solutions

The machines in the system were previously used in a test factory for another company. The test was conducted for a few months before it was closed down and Martinsons bought the machines. The system and layout in the test were copied to Martinsons' factory.

The original plan for the shipping area was to pack the littera directly on to the trucks. The truck would back inside the building, and the sides would be opened. This plan did not work for the production; there was no space for sorting. Thus, the shipping was changed to the situation current.

2.2.4 Location

The factory that is producing crosslam is located in Martinsons' main facility in Bygdsiljum, Sweden. The factory is placed in northern Sweden to have easy access to the forests that Martinsons uses in the sawmill. The factory that produces crosslam is named factory 5. Figure 6 shows an aerial view of the entire sawmill, where the buildings are marked with red. Factory 5 has a blue colour. The newer parts with the CNC and shipping is marked with a darker blue.

Figure 5: The bridges over the conveyors

Figure 6: Aerial view of Martinsons´ facility in Bygdsiljum (Lantmäteriet/OptiWay AB, 2017, slightly modified)

3 Theoretical Framework

The project uses a scientific basis as motivation for the decision, to avoid potential risk in production development. In this chapter, the theoretical basis for this project presented. Initially, Industrial design engineering is described, followed by a description of LEAN, high mix and low volume production, efficiency and lastly ergonomics.

3.1 Industrial design engineering

The project is the degree project for a master degree in industrial design engineering. Therefore, it is important to understand what industrial design engineering is.

Throughout the world, there are many kinds of production systems (Røvik, 2008). The systems can be graded based on to what degree they are focused on the workers. The engineering side and the human side are considered to be the extrema points of the scale (Røvik, 2008). Taylor (1916) and his production philosophy, stating that the worker is a mechanical part, can represent the engineering side. The parts are optimised or replaced to achieve higher production (Taylor, 1916). The human side wants to prevent any damages to the worker and ensure that he can live a healthy life (Ashton & Maier, 2007).

Industrial design engineering is the best of both sides, a combination of human and industrial demands (Ashton & Maier, 2007). Industrial design engineering designs with the human in mind. One of the best solutions is one that simultaneously eliminates the health risk and improves the productivity (L. Abrahamson, personal communication, 29 January 2016). The human should always be in the centre of the design (Ashton & Maier, 2007).

3.1.1 Production development

When designing a production system with an industrial design engineering angle, several aspects should be considered (Bellgran & Säfsten, 2005).

First, the future should be considered. The market may change, demands can increase, or the government may introduce new regulations (Bellgran & Säfsten, 2005). A well-designed system is flexible and can adapt to the changes, both short and long-term (Bellgran & Säfsten, 2005). The situation in the factory must also be taken into consideration (Phillips, 1997). How will the factory affect rivers, forest, air quality, local infrastructure etc. in the proximity of the factory? The climate should also be considered, For example, if there a lot of snow in the winter (Phillips, 1997).

Lastly, the working environment should be considered. Sadly, many companies forget this aspect when designing a new system (Bellgran & Säfsten, 2005). By focusing on the working environment can sick leave be avoided, that save time and money (Sarkar, Dev, Das, Chakrabarty, & Gangopadhyay, 2016).

The workers need to be involved when designing a new system (Ashton & Maier, 2007). The workers have the highest understanding of the system, knowledge that can make or break the solution (Ashton & Maier, 2007). If a solution fails to solve the problems and the workers reject it, they may develop an "immunity which makes future changes more difficult (Røvik, 2008).

3.2 LEAN

Based on the reports from Martinsons, the current problem is a lack of capacity in the shipping and several minor adjustments. lean is a subject that eliminates wasted time to achieve a continues improvement.

Lean is not a tool or a toolbox used to improve the effectivity of a factory (Liker, 2013). Instead, it is a culture where everyone in the system, on all levels, is continually working on improving the system by reducing the waste. Lean was developed by Toyota after the World War II and was used to help Japan recover from the second world war (Liker, 2013). The essence of lean is to discover what activities adds value to a product from the costumer's perspective. Any other activity is considered waste and should be removed (Liker, 2013). However, that is only one part of lean. Lean exists on four levels: problem-solving, people and partners, presses, and philosophy (Liker, 2013). Liker divides the levels into 14 principles that a lean company should follow to have a "real" lean system.

Below are Liker principals paraphrased divided in to the levels.

Long-Term Philosophy

Principle 1:
Have a long-term plan, even at the cost of short-term plans.

The Right Process Will Produce the Right Results

Principle 2:
Have a continuous process flow that brings the problems to the surface and deals with them directly.

Principle 3:
Only use what is necessary and use a "pull" system. In other words, only produce what is ordered.

Principle 4:
Strive for an even workload, *heijunka*.

Principle 5:
Create a culture that stops the processes to solve problems, to have quality right from the start.

Principle 6:
Standardise tasks and preformats to save time. Strive for continuous improvement, *kaizen*.

Principle 7:
Use visual control 5S, discussed further in Chapter 3.2.2.

Principle 8:
Use the right tools for the job, tools that are reliable and serves the workers rather than forcing methods on the workers.

Add Value to the Organization by Developing Your People

Principle 9:
Develop leaders that live by lean philosophy and passes it on in the organisation.

Principle 10:
Develop excellent people and teams in the organisation, who understand the company's philosophy.

Principle 11:
Develop good relations with subcontractors and help them improve by putting pressure and challenge them. They should, in the best-case scenario, also use LEAN.

Continuously Solving Root Problems Drives Organizational Learning

Principle 12:
Do not merely trust the reports of a problem. Go and see the situation first-hand. Know the system like the back of your hand.

Principle 13:
Make the decision carefully and consider all options. Implement the solution rapidly when decided.

Principle 14:
Always reflect on the good and bad thing that happened. Strive for continuous improvement to become a learning organisation

Many companies focus on problem-solving (Liker, 2013). Companies that do not use all aspects of lean smaller results compared to a company that introduced lean of all levels (Liker, 2013).

3.2.1 The three wastes

Waste reduction is essential in lean (Liker, 2013), but what does lean define as waste? Lean identifies three kinds of waste: Muda, Mura and Muri (Womack &Jones, 2010).

Muri is the waste that occurs when the demand of a machine or worker is close to its maximum capacity, where the risk of defects or breakdowns is more common (Liker, 2013). Mura describes unevenness in the production schedule, volume or process time. Custom ordered parts generate Mura, as the variations add unevenness with setup time for the tools (Jina, Bhattacharya, & Walton, 1997). The last waste, Muda, is a result of Muri and Mura. Muda describes seven wasteful activities in the production. In later years one additional waste has been added (Womack & Jones, 2010).

1. Overproduction- Producing more than necessary
2. Waiting- for something to happen
3. Storage- to store more than necessary
4. Movement- unnecessary movement while the co-workers are doing their jobs
5. Redoing- Repairs and reworks that do not add value
6. Overwork- To do more than what the customer wants
7. Transportations- Unnecessary transportations

+

1. Not using the entire creative ability the workers have.

By removing waste in the system, the productivity can improve, and the workload can become more even (Liker, 2013). The workers always have material to work without being overwhelmed. Lean calls it *Heijunka*. *Heijunka* is one of the most important aspects of lean (Liker, 2013).

3.2.2 5S

Lean uses 5S to organise the workplace and the handling of materials (Hirano, 1996). 5S is a tool to gradely organise and structure the use of material, space and cleaning. 5S consists of 5 points that can help with the organisation (Hirano, 1996).

- Seiri (Sorting) – Remove tools and material that is not needed and only keep the necessary.
- Seiton (systematise) –Place material and tools so reaching them is easy when needed.
- Seiso (Clean)- Clean the workplace regularly.
- Seiketsu (Standardize) – Standardize the daily routines. Use checklist and "to-do" lists to visualise all the moments needed and completed moments are visualised what has already completed.
- Shitsuke (self-discipline) – Engage the workers themselves to implement the four above components, have the worker take own responsibility for them

The fundamental motivation for 5S is, as for lean, to involve everyone in the improvement of a workplace (Jina, Bhattacharya, & Walton, 1997). 5S makes it possible for everyone to find the problems and solve them. If 5S is fully implemented, the workers and the leaders can quickly see what is in need of improvement and re-reorganisation in the workplace (Hirano, 1996).

3.3 High mix/low volume production

Martinsons' products have a high variation between separate two litteras, resulting in a High mix/low volume system. High mix/low volume systems have some key factors that identify them and restrict what can be done to solve the problems.

Many production systems can be described as a High Volume/Low Mix system (HVLM) or as a High Mix/Low Volume plants system (HMLV) (Jina et al., 1997). Jina defines mix as for how unique two products are to each other, and volume describes how many products are produced in the system. The difference is that an HVLM production produces to stock, while an HMLV production is producing directly to the orders (Jina et al., 1997). The variations result in a difference in total possible volume. The throughput in a lean system is roughly in the hundreds of thousands to millions, while the throughput in HMLV production is thousands of units (Jina et al., 1997). The last relevant difference, for this thesis, is that an HMLV production often has their entire production in the same building.

One of the problems in an HMLV is that turbulence and variations, Mura, have more significant effects on the production than in HVLM production. The four turbulences are schedule, product mix, volume and design (Jina et al., 1997).

Lean has many tools that are used in production and lean is most useful in an HVLM production with few variations (Irani, 2011). An HMLV system has several variations. Therefore, some tools cannot be used in an HMLV system (Irani, 2011). For example, tact time and value stream mapping cannot be applied in an HMLV, as may exist significant disparity in the process time between different products. Other tools can always be used. Like worker involvement, visualising the management, standardise the work and introduce 5S (Irani, 2011).

3.4 Flow and resource efficiency

Martinsons wants to have the press decide the pace for the entire system. It means that the flow efficiency must be high. This section explains how the efficiency of a system can be described.

Two methods are used to describe the efficiency of any system (Modig & Åhlström, 2015). The first one examines the value-adding time compared to the total time in the system. This efficiency is called flow efficiency. The second method, which analyses the utilisation of the machines or operators, is called the resource efficiency (Modig & Åhlström, 2015).

To improve the flow efficiency the waiting time must decrease. One way to achieve this is to remove any buffers in the system and only produce when the next process is available (Modig & Åhlström, 2015). The lead time would decrease and increase the flow efficiency. Resource efficiency depends on the utilisation of the machines. The machines must always work, so a buffer is needed to ensure there are new parts for the machine at all time.

The definitions for Flow-/Resource Efficiency present a paradox. They are the opposite of each other. It can be visualised in the efficiency matrix, see Figure 7. The matrix has two axes that visualise the system efficiency from the flows and the resources. The matrix enables two descriptions of the current state of the system. All systems have some kinds of variations (Modig & Åhlström, 2015), especially in systems with an early customer order point. The variation may be present in the demand, the products or the process. In the matrix, the variations are represented by a line that reduces the possible space, see Figure 8. As the variation increases are the line moved closer to Origo and reduced the possible space and freedom for the system. All systems have some variation in some way.

The dilemma is, If the flow efficiency is high, the resource efficiency must be reduced to fit inside the possible space. The machines prioritise the flows and reduce lead time at the cost of utilisation. The opposite is true for resource efficiency. Both efficiencies could be high Without the limitations placed by the variation. As all systems have variations, a priority must be made. What is more important, the utilisation of the machines or the flows? Modig & Åhlström believe that the focus should be on the flows and then the resources. The variations must be eliminated to achieve high productivity in the system (Modig & Åhlström, 2015).

3.5 Ergonomics

Martinsons wants to improve the working condition in the shipping area. Therefore, the ergonomics are examined.

The definition of ergonomics is *"…the scientific discipline concerned with the understanding of interactions among humans and other elements of a system…"* (International ergonomic association [IEA], 2017). In everyday terms, it describes how the human position and the environment affect the human body. Ergonomics consists of three main parts; physical ergonomics, cognitive ergonomics and organisational ergonomics (IEA, 2017). It cocomposers several subjects like the biology of a human physiological, psychosocial, social, and cultural factors (Bohgard et al., 2008).

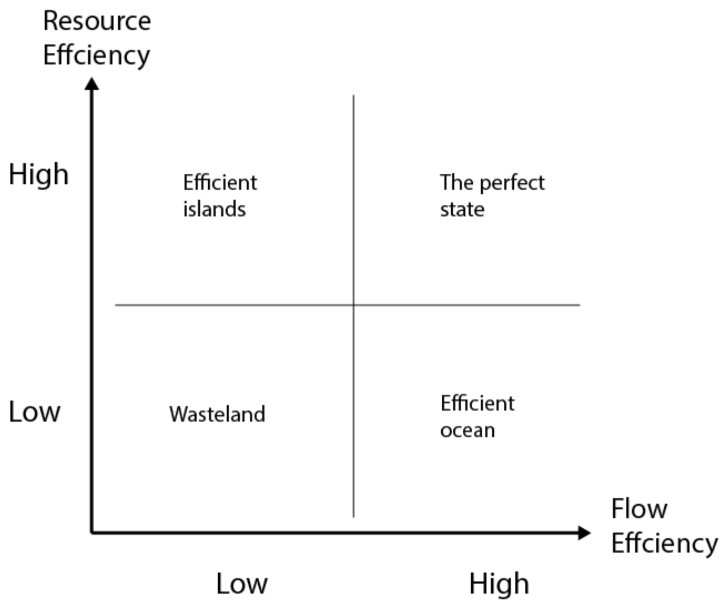

Figure 7: Efficiency matrix (Modig & Åhlström, 2015)

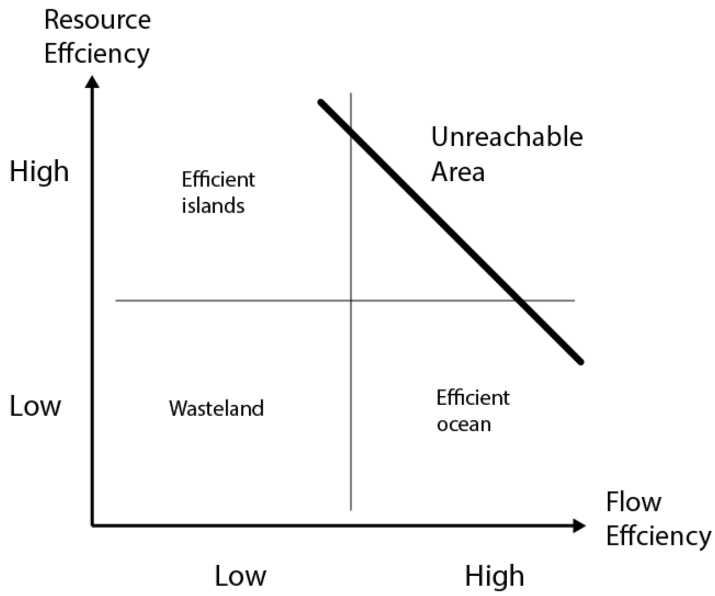

Figure 8: Effects of variations (Modig & Åhlström, 2015)

3.5.1 Physical Ergonomics

The physical ergonomic contains all the "hard" factors from the environment that affect a worker in the system. Some example of this is the working position, movements, noise, light and temperature (IEA, 2017).

The employer's responsibility

The employer has the ultimate responsibility to ensure that there are no of damages for the worker. The workplace should be designed to avoid any risks of accidents and to avoid extreme positions of the body, especially for the back (Belastningsergonomi [AFS] 2012:2 6§). If workers develop any problems connected to the work, the employer is responsible for giving rehabilitation (Arbetsanpassning och rehabilitating [AFS] 1994:1).

Manual handling

The definition of manual handling is *"Any shipments or movements of loads where one or more workers lift, lower, shoot, drag, carry or move a load."* (ASF 2012:2 3§, my translation). Five factors are central to if a situation with manual handling is riskful for the worker (ASF 2012:2 Appendix A). The more of the factors that exist in a workplace, the less the recommended maximum load is.

The characteristics of the load
The risks of injuries are higher if the load is large. However, other factors like size, shape, how the object is lifted and if the object is hard to lift or handle.

Physical Demands
The risks for the worker increase if the workers need to twist and/or bend their backs. This factor also includes if the position is balanced.

The design of the workplace
The workplace should be designed to avoid the risks of an accident that can injure the worker. The floor can be uneven and slippery that may cause falls. The may not be enough space to handed the objects with a good posture. Is the temperature at a comfortable level or is it cold? To prevent fall damage must all heights above 0.5 m have a fence at least 1m high, while heights above 3m should have a fence 1.1m high (AFS 2009:2 67§).

Organizational requirements
The worker needs to have brakes to rest to prevent accidents. The risk also exists if the worker needs to lift objects over long distances and has many individual tasks.

Individual factors
This factor questions if the worker is suitable the task. Does the worker have the reaches and strengths to lift and place objects? Is the clothing to warn or do they hang loose so they may get caught in machines? Lastly, does the worker have the skill and education needed for the task?

In addition to normal accidents, these risks can cause musculoskeletal disorders (MSD). The signs of MSD are pains in the back, neck, shoulders and other affected parts of the body. MSD can remain for many years (Samaei, Tirgar, Khanjani, Mostafaee, & Hosseinabadi, 2017). Many different studies have determined the fact that working position and manual handling can cause MSD (Trinkoff, Lipscomb, Geiger-Brown, & Brady, 2002).

Apart from the medical and ethical problems with risks for MSD, they can cause economic problems for a company by the loss of work time, sick leave and lower productivity (Sarkar et al., 2016). The factors that contribute to MSD are awkward postures, repetitive motions, and lifting heavy loads (Sarkar et al., 2016).

Inactivity and its effects on the body

Most of the time, when a workplace is improved to avoid MSD the physical demands on the workers are lower by automatization (Winkle, 1989). The primary reason for it is not to lower the demands but to avoid humans in the system. Compared to machines, Human workers are unreliable, has a low efficiency and requires more pay (Winkle, 1989). To achieve higher productivity workers are changed from artisans to operators. The change improves the productivity and removes loads from the worker to lower the risks for MSD. However, the levels of MSD increased anyway (Winkle, 1989).

Winkle discovered that low physical stress on the body also causes of MSD. Workers who sit long periods of a day, >4 hours, are exposed to the same risk as workers who stand up large parts of the day, >6 hours a day, despite the fact that standing work puts higher loads on the body (Winkle, 1989). This relation looks like a U, with high risks at both low and high demands and low at moderate levels, see Figure 9. This

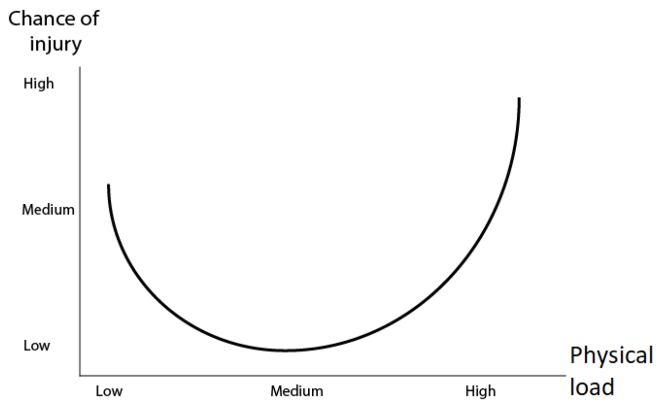

Figure 9: Relation between physical stress and MSD (Winkel, 1989)

relation exists in other body parts too (Winkle, 1989). Ergonomic changes should therefore not eliminate the stress, but to optimise it (Winkle, 1989).

Temperature

The temperature in a work environment can be divided into three sections; Cold (below 10C°), Neutral (10-30C°) and warm (above 30C°). Each section affects the human body differently. The neutral section has no or small effects on the human body, while both cold and hot have more prominent effects (Arbetsplatsens utformning [AFS] 2009:2 29§). The draught must be taken into account when measuring the temperature. If there is a draught, the temperature is perceived lower than temperature level is measured. Temperature-related problems can occur earlier in areas with a higher wind speed compared to a windless environment

In a cold environment, the first effect of the temperature is a lower comfort level for the worker. If nothing changes in the temperature, fine motor skills are affected, and more faults will be made (Johansson et al., 2008). At prolonged exposure to cold environments the risk of tissue damage increases. The effect of temperature on the mental performance is not fully researched. However, the number of accidents increases at lower temperatures (Johansson et al., 2008). If the worker has an active work, the temperature can be lower (14-15C°), compared to if the worker is sitting down (20C°), as physical work warms the body (AFS 2009:2 30§). The responsibility to protect the workers from draught from gates, doors and other similar areas is the employers. If the difference in temperature between two areas is large, it is more important to avoid the draught between them (AFS 2009:2 31§).

3.5.2 Organizational ergonomic

Organizational ergonomic describes the social environment in a workplace. It analyses stress, psychosocial factors, teamwork and the relations between the workers in the system.

Mental health

Mental health problems are the most common reason for sick-leaves in Sweden and the world (Carl von Essen, 2016). In 2015 were 41% of all sick days in Sweden were caused by the mental health. In 2005, the number was 28% (Carl von Essen, 2016). To analyse a person's mental health are five aspects used (Thylefors, 2008).

- Confidence and self-knowledge-describes the ability to understand ones' strengths and to accept one's flaws
- Self-realization-the ability to do more than just "living", to have something you can be proud of
- Independence- The ability to be unique and not be influenced by other people
- Reality Perception-How well a person can understand other people's feelings
- The ability to master existence-A Summary of the most critical aspect of the other points.

Psychosocial working environment

The term Psychosocial was created by Erik H Erikson (1959) and reflects his, and many others, opinion that people are formed and developed by their environment. They see relations with other people as critical to a healthy mind, even for adults.

Psychosocial describes the need rather than a specific part of the working environment. It also describes the individual interaction with the entire environment, not a specific part of it (Thylefors, 2008). Five main factors decide how well a psychosocial work environment is perceived. These factors determine how the mental health of the workers is affected (Thylefors, 2008).

- Self-control at work-The ability to control the pace of work with other people and the technical system
- Positive working climate-The relation to the team leader is essential for trust and a democratic communication
- Stimulus in the work-the workers are stimulated and satisfied with their work and feel that they have the opportunity to improve and grows as a person
- Good working community-A good community in the workplace is important to avoid stress and solve problems and conflicts
- Just workload-The demands on the workers are just in line with the capacity of the worker. They are not too low or too high.

One way to analyse the Psychosocial working environment is to use the demand-control model, Figure 10. The model has three axes. The support axis represents social climate and community, the demand axis that represents the workload and the freedom axis that includes self-control and stimulus (Thylefors, 2008). This matrix can describe any working situation. If the demands are high with no support or freedom, the situation is a risk to the mental health and may cause stress. The demands on the individual worker are too high.

The opposite, a developing situation, has high demand, freedom, and social support. In this scenario, while the demands are high, the worker has the resources to solve them and can improve under the demands. The freedom to decide how to work and the social support acts as a buffer to the risks (Thylefors, 2008).

Stress

One common problem in many businesses is stress. Stress occurs when the demands of a person are higher than their capacity to deal with them, while they receive no support from the community. However, it can also occur if the worker works alone for large parts of the day or if the worker does not have many social relations. However, not every human is the same. A situation that one person can develop stress from can be considered challenging and developing by another. Stress is a typical reaction for humans, as it was important for the early survival of the human race (Ingrid, 2014), by giving the extra strength to complete a task. Nowadays, stress is considered one of the most prominent problems in a modern society.

The first biological effects of stress are that the blood pressure, pulse, and the levels of adrenaline are increased, making the person stronger (Thylefors, 2008). Some bodily functions that are considered unnecessary at the time are suspended casing discomfort. By removing the stressful elements, the body can recover and return to normal. (Ingrid, 2014) Otherwise, the victim may develop depression, anxiety, infectious disease, sleeping problems, and a decreased appetite (Thylefors, 2008). It is always best to prevent stress from occurring rather than dealing with the effects (Ingrid, 2014).

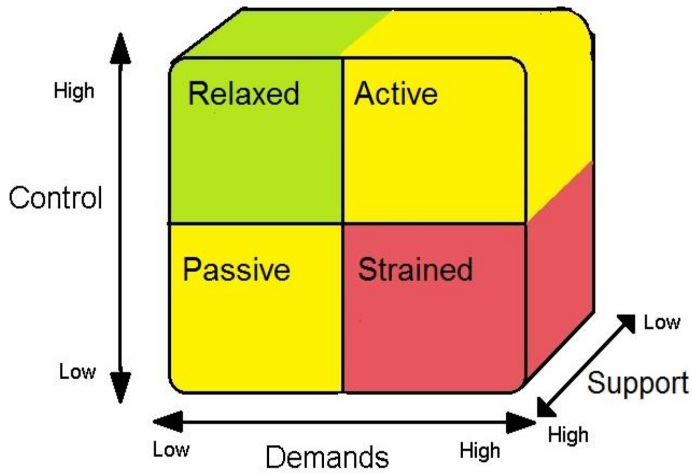

Figure 10: Demand control model (Inspired by Thylefors, 2008)

4 Method and Implementation

When analysing an entire system, the task can feel overwhelming. If the project is divided into smaller sections, the project will feel more manageable. This chapter describes how this project was divided and which methods and the tools used in each part.

4.1 Process

This project follows the projects circle (Johansson & Ranhagen, 1995). The projects circle gives a standardised way of working with a self-checking to improve the result. The circle consists of eight steps that should be repeated several times with a different focus each time Figure 11 visualises the concept with the repetitions where the red area represents the focus of the repetition. The steps used for this project are presented below. In comparison to the original version, steps 7 and 8 have been changed to more appropriate points, as the original are outside the scope of the present project.

1. Plan for change
2. Conduct diagnostics
3. Formulate goals and specifications
4. Seek alternatives
5. Value and choose the final solution
6. Detailing the final solution
7. Present the results
8. Reflect on the project

This project uses five repetitions. Each repetition ends in a stage gate. Repetition 0 had the project planning. The first real repetition, context immersion, was used to investigate the current stage of Martinsons' production. The

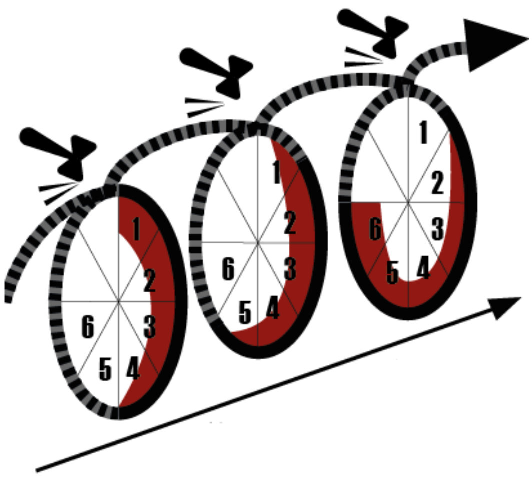

Figure 11: Project spiral used in this project (Johansson & Ranhagen, 1995)

second repetition analysed the problems to find the cause. Also, to have a better foundation for the solution was literature analysed. The third repetition was used to find several alternatives to the solutions for the problems found in the second phase. The fourth and final repetition developed the solutions and decided the final result. The repetition ended with the presentation and finalising the report.

4.2 Project planning

A Gantt chart was used to schedule the time for the project. The available time was allocated to the different phases. The planning was done on a day-to-day basis. Lastly, the preliminary deadlines were added. The deadlines include the official deadlines set by LTU, for instance, the halftime presentation and the final report, and also other important dates to maintain progress in the project, like completing the literature review.

Once a week, an email was sent to the contact at Martinsons with an update regarding the week's work and the status of the project. At each stage gate, a meeting with the supervisor at LTU was held to discuss the situation of the project and the what the following were.

4.3 Context immersion

Understanding the current state and seeing how the system works is a major part of any project. Several methods were used to facilitate the gathering of the data.

4.3.1 Observations

Observations are a method with a broad scope of use. Observations are useful in a vast variety of ways, for instance when determining how a specific assignment is done and when examining how the whole system works. Compared to other methods, observations render a more natural result. Observations are also used to see what the workers do and if they are ignoring any written standards and routines (Osvalder, Rose, & Karlsson, 2008).

In this study, observations are used to understand the system on a more fundamental level. The results of the observation were an increased understanding of the system and also information on the current stage. The system was observed on two separate occasions; each observation was one-week long. All observations were during the day shift. The first was primarily aimed at understanding the context and how the system worked. The observation started off by observing the workers without interrupting them. Later, a worker was followed and interviewed, see next section. During the visits, the demand on the system was 3, on a scale from 1-10, while normal demand was around 8. The second observation was conducted four weeks after the first one. The objective was to understand the working conditions and the ergonomic problems. It was conducted as the first observation. The only change was that a worker was filmed while working.

4.3.2 Interview

While observations give an objective view of the system, an interview is a subjective method. The workers are asked questions about the system. With the answers, the workers' opinions about the system can be analysed. Interviews can be divided into two types; structured and unstructured. The unstructured can be used to explore the context in a situation. One of the interview's strengths is that follow-up questions are possible. With this kind of interview, more feelings and opinions can be found. Compared to the unstructured interviews, the structured interview is less free in the response. The questions may have a scale for assessing levels of, for example, stress at the workplace. As a result, the results are more data-driven, compared to an unstructured interview with more feelings (Osvalder et al., 2008).

Interviews are an easy and flexible tool to facilitate an understanding of the context of a situation. The most significant issue is to succeed in documenting all the data, as a person can reveal much important information at the same time. In this project, two kinds of interviews were conducted. One was during the observations, aimed at gaining a better understanding of the situation. The interviews during the observations were unstructured, with no questions prepared. The aim was to have a conversation with a genuine interest in the system. The interviews started with pleasantries and asking how things are going. The conversation was then steered towards the specific subject in a natural manner. The interviews were in the system while the production was active. The people interviewed were workers in the shipping, CNC area and the CAD drawer

The second interview was a group interview, aimed at validating earlier observations and finding more specific data. The group interview was designed to validation of the context to generate a specification and proximity analysis. The initial step was that the workers discussed the problems they see in the system today, in order to confirm the observations and discover new information. Secondly, a specification was generated and graded. Lastly, the workers were asked to do a proximity analysis. Three persons participated in the group interview. Only one participant was a worker from the floor. No more than one could participate as the production leader believed it would affect the production.

4.3.3 Proximity analysis

A proximity analysis is a tool to evaluate the relations between different stations in a system. A proximity analysis is most commonly used to find an optimal layout for the factory. The relations are graded on a scale from dangerous to required (Phillips, 1997).

A five-graded scale was used to grade in the proximity analysis, see Table 1. The proximity analysis was used to understand how the parts of the system need to be close together, and what proximity should be avoided. It was also used to evaluate the concepts.

Table 1: Scale for the Proximity analysis

5	Critical	Must be fulfilled
4	Important	Should be fulfilled
3	Neutral	Not important
2	Unvented	Should be avoided
1	Dangerous	Must be avoided

4.4 Literature review

A literature review regarding the subject was performed to validate the results. The sources used were scientific articles, books and published master's thesis from LTU. The databases used were Scopus, Libris and to some extent Google Scholar.

The searches on the databases started with one keyword, that was searched for. To narrow the results were extra keywords added until the results were fewer than 30. After reading the summaries, the relevant articles were downloaded for further examination. Below are two examples of the searches presented:

- MSD (7285)
  - Working and posture (153)
  - Backs and neck and shoulder (29)
- Lean (82 082)
  - High mix low volume or HMLW (17)

The books were found by searching for a specific subject or by recommendations from the supervisor at LTU. Lastly, the master's thesis was used to find interesting articles directly.

4.5 Analysis of the current state

At the end of the context intermission, the current system was analysed. Mostly, the gathered data was reviewed, discussed, and documented. However, some specialised methods, like OWAS, hierarchical task analysis and, a survey, were used to study specific subjects as well.

4.5.1 Ergonomic analyses

There were two reasons for examining the work conditions. First, industrial design engineering works to improve the conditions for the worker. To not analyse them would be to betray the principles of the profession. Secondly, an improved working condition lowers the risks for the workers. The utilisation of the worker can be improved by avoiding sick leaves, lowering personal capacity, and avoiding costs to rehabilitate the worker. Three methods were used to describe the ergonomic situation at Martinsons. The temperature was measured, the working position described by an OWAS analysis and a survey was used to describe the psychosocial environment. Martinsons has worked hard with the sound levels. Hence, there was no need of examining them.

OWAS

To analyse the working positions in the shipping an OWAS analysis, Ovako Working Posture Assessment, was used (Louhevaara & Suurnäkki, 1992). The method starts with one worker that is recorded during a normal working day. The recommended length of the film is 10-30 minutes. The film is later used with a chart to analyse the position of the worker's limbs every 10-30 second. Each evaluated moment is described as a four-digit code: the position of the trunk, arm, leg, and the loads. The method has been expanded by Stroffer to include the position of the neck and head (1985, referred in Brandl, Mertens, & Schlick, 2017). The positions for the back, leg, arms and the load are then used to grade the position on a scale 1-4. The results are analysed statistically for the amount of time each body part was in a damaging position.

Two positions analysed by the OWAS are the sorting and the packaging positions. Activities at these positions involve movement and active work on the panels and litteras. The gluing do not have these problems as the work is more operating of machines. The films were 12-15 minutes long and analysed every 10 seconds. The analysed periods are assumed to be representative of an entire day's work and the workers in the shipping are spending 1/3 of the day with packaging. The workers are aware of the filming. Any changes in the working routines compared to normal are considered irrelevant.

OWAS can easily be used in situations with much movement, compared to other methods. The result is easy to compare with other stations. Lastly, the film can be used in other methods, making the visits more efficient.

OWAS is an easy way to conduct a screening of workplaces and can easily be used to compare different stations. An OWAS is a flexible tool that works well in combination with other methods. The methods RULA and REBA (Mcatamney and Corlett, 1993; Hignett and Macatamney, 2000) were not used, as the work in the shipping is moving and RULA and REBA require fixed working positions.

Temperature

Thermometers in the factory were used to measure the temperature. One was located in the packaging area close to the gates. The other was placed in the gluing area. The wind speed, or draught, was not possible to measure with the instrument, but the rough levels were asked for in the interviews.

Survey

All the workers in the factory were given a survey regarding the working environment (Osvalder et al., 2008). A survey is both an easy and difficult method to use: easy, as it can, on short notice be used to receive information from many participants, Hard to use as there is no dialogue with the subjects and a lot depends on the phrasing of the questions. For example, a question can be interpreted in different ways, especially if the question is guiding the participant's thinking in a specific direction, or if there are any difficulties to understand the question (Osvalder et al., 2008).

The survey was four pages long with 16 main questions, with some follow-up questions. It consisted of three parts that examined basic info, psychosocial factors and the ergonomic risks. Workers in both the gluing and the packaging section were handed the survey, to enable a comparison of the parts. The results were analysed and presented statistically. In Appendix 1 the survey is attached. Most of the questions asked the workers to grade a statement on a scale 1-10 or select one of several alternatives. They had the possibility to comment on their answers, if needed, to facilitate a deeper understanding of the situation. The survey ended with two open questions.

OWAS only analyses the working position; more information was needed to see if they are any damages because of the positions. It was also used to see if sound or light is an issue. The survey was also necessary to examine the psychosocial environment.

4.5.2 Capacity

For the current system, both the actual and theoretical capacities were determined. For the actual level of production, the produced volume was compared to the planned volume. The theoretical capacity of the machine was calculated as the cycle time for the press, CNC-machines, and sander. The time consumption of the cycle was then used to calculate the capacity of panels/day, (1 day=2 shifts=16 h). The time consumption for each cycle was calculated for the second CNC assumes that the tools have a maximum speed, perfect sharpness and that there are no incidents. The actual time will be longer.

4.5.3 Hierarchical task analysis

Hierarchical task analysis (HTA) is a tool that is used to visualise and analyse the process of carrying out a specific assignment. It starts with one primary task that is split up into sub-tasks, which are then analysed in turn until the entire actual actions have been covered (Osvalder et al., 2008). Usually, 4-8 sub-task are used, but it can vary in need of a more precise image.

The HTA was used to clarify what the routines in the production are. It was carried out on the CNC and the shipping. The reason for doing an HTA was to simplify what the operator is doing and see where the ergonomic risks are.

4.5.4 Event tree analysis

An event tree analysis (ETA) is used to understand the reasons behind a problem (Osvalder et al., 2008). In many cases, there are several reasons behind a problem. An ETH starts with the main problem and discovers the underlying reasons for it. Moreover, gates with and/or statements are used to investigate the chains of fails that cause the problem. If two or more events must happen simultaneously for the system to fall, the gate is an *and-gate*. If only one event is necessary, the gate is an *or-gate*. A safe system has many *and-gates*, as several events need to happen at once to cause the problem.

After the data gathering, the main problems were decided by the group interview and the observations. The first major problem was selected and analysed using the HTA, followed by the sub-cases. When all the cases of a problem were determined, the HTA was repeated for the next major problem.

The ETA was used to find the cause of the problems in the shipping by breaking down the problems into more manageable cases. ETH is an easier way to find simple solutions.

4.5.5 Requirements specification

Requirements specifications are used to organise the demands and the essential aspects of a solution. They can be used to grade the results and steer the solution to be more suitable for a specific system (Osvalder et al., 2008). The specification is one of the most important documents in any project. It grades what the solution must fulfil and how important the demands are compared to each other (Osvalder et al., 2008). The specification is used to grade the solutions to find the best solution for the problem.

The specification was generated through a combination of interviews, observations of the workers and the group interviews. The problems were discussed and formulated as a demand, that the project could use, after a short discussion. Lastly were the specifications graded on how important they are in the system. The scale had three rankings that each had a different definition, see Table 2.

Table 2: Ranking of the Specification

Ranking	*Definition*
3	Required
2	Important
1	Normal

4.6 Ideation

Once the data had been gathered, and the roots of the problems were defined the next step was to solve them. This creative phase is one of the more exciting phases, seen from an outside perspective. But it can be hard to find new and innovative solutions. Therefore, Methods can be used to improve the creativity to achieve more unique solutions (Wikberg-Nillsons, Ericson and Törling).

An idea that did not work is not a failure; it is a successful way to remove an idea that was not good enough. "getting it right the first time is not a realistic objective" (Thomke & Reinertsen. 2012).

There was no time to involve the workers in a workshop to create new concepts, as Martinsons needed all-hands-on-deck in the factory. Instead, the workers and leaders were asked regarding possible solutions during the observations.

4.6.1 Workshop at LTU

To utilise one of the resources at the university was a workshop was conducted with students who have no insight into the current system. A workshop is comparable to group interviews but with more involvement. The most significant difference is that group interviews ask the subjects a question, while in a workshop they are asked to solve a problem. A workshop is a creative method, and the participants are free to find the solutions to the problem (Hanington & Martin, 2012).

The workshop was conducted November 2017 at Luleå University of Technology with six students. The subjects were primarily from the program industrial design engineering. The workshop started with a quick introduction of Martinsons, crosslam, the current state and the problems found in the production were presented. The participants were then asked to find solutions to the problems.

The main reason for the workshop was to avoid any bias that might exist in the factory. The production leader has presented some alternatives to the workers. During the interviews, it was observed that the workers have "tunnel vision" based on those ideas. Any creative method would have difficulties to overcome this problem, and no new ground-breaking concepts would have developed. The students have almost no bias toward the existing system and potential solutions and are hence more open to thinking outside the box.

4.6.2 Benchmarking

A benchmarking can be considered an accepted form of industrial espionage. A benchmarking is in its most basic form observation of another company's system (Johansson & Abrahamsson, 2010). It is used to analyse how other people have solved the problem and what they have not done.

Industries that were interesting for a benchmarking visit was those that were working with wooden products and vast amounts of sawdust or companies that were handling large products. After contacting them and asking for permission the visit was carried out exactly like a typical observation. The benchmarking aimed to find differences and similarities to describe the problem at Martinsons, but also to be inspired to find new solutions. Three companies were benchmarked: Snidex, Burträsk, that produces window frames. Nordick light, Skellefteå, that produces light fixtures, and lastly GastampHardteck, Luleå, that are producing metal details for cars.

4.6.3 Brainstorming

The workshop and observations resulted in several ideas. By combining the ideas from the workers and the workshop in private brainstorming, concepts were formed. It was done to take aspects of different ideas and combine them to produce several solutions. The proximity analysis was used to help to create optimal layouts.

The brainstorming was done by the project member alone. The concepts contain ideas from both the workers and the workshop. The first round consisted of combining ideas earlier phases to concepts. In the second round, the concepts were based on names or phrases (Wikberg-Nillsons et al. 2013).

To receive feedback, the concepts were sent to Martinsons for review. After a brief discussion with Martinsons, some concepts were removed, based on feasibility and how unique they were. Changed were made when necessary on the remaining concepts.

4.7 Final evaluation

In the previous phase, several concepts were generated. All of them were interesting in some way or another. This section describes how the final solution was decided.

4.7.1 Detailing

The concepts from the last phase were mostly sketches and ideas. To compare them to each other, all concepts must be on a similar level of detail. Otherwise, it would be unfair to some concepts.

There were two periods of detailing the concepts. The first one was before the value matrix, with focus on adding details to the concepts. To fairly compare the concepts, all the concepts must be on the same level of detail. The details were the sizes of the areas, placement of cranes and distances between stations. Most of the details were in 2D, as they were used to explore the opportunities. However, some 3D elements were created to increase the understanding of details. The second detailing was after the value matrix, focusing on the final solution. While the earlier images were used to explain the layout, the new images were used to express them. To increase understanding of the concepts and examine what investment was needed, a 3D model was created for each concept, with the machines, people and as many details as possible. The final 3D models received improvements compared to the original concept.

4.7.2 Value matrix

A value matrix was used to make the final evaluation (Johansson, 1995). A value matrix uses the specification to decide which solution that fits the demands the most. The aspects are compared and graded depending on how important they are. The concepts are then analysed regarding how well they fulfil each specific requirement.

The fulfilment score and grading of the specification are then multiplied for each specification and added together. The higher score, the better the concept fit the specification. However, other aspects may affect the final choice. Was the score of several concepts almost the same? Can a score difference of only 5 points be trusted? Was the highest score vastly different from the others? Why was it so? As with any method the result must be analysed independently.

One of the strengths of a value matrix is that it is an objective tool. By comparing the concepts to themselves, the demands are the only deciding factor. The grading must be objective for all concepts to avoid favouring any concept.

In this project, the value matrix was used to compare the concepts. As stated, it is useful to receive an objective result, which is important in this project as there is only one member. With the matrix, the concepts are equal among themselves, and the results are less affected by opinion. For grading the of concepts, a scale with four levels, 3-6, were used. The span 3-6 is used to avoid extreme differences in the ranking. If the scale were 1-4, the best result would be four times better than the lowest, compared to two times with the used scale. This prevents one aspect from deciding the result. Each specification has an individual grading, but it can be generalised to the fulfilment of a specification in percent. Table 3 shows an example. The scale is not linear; the highest rank 6 demands more of the concepts than the rest, to ensure that only concepts that have full fulfilment receive it.

Table 3: Example of the fulfilment scale

Rank	***The fulfilment***	***Example:*** minimise lifting with the crane
3	0-30%	All transportation requires the crane
4	30-60%	Only one significant transportation requires the crane
5	60-95%	Only one quick and short lift requires the crane
6	95-100%	All transportation is without the crane

4.7.3 Economic calculation

Martinsons is interested in the payoff time. The payoff time is the point in time when the accumulated profit caused by the investment exceeds the actual cost of expansion. The use of the payoff time is to evaluate which concept is more efficient for returning the investment.

The payoff time calculation requires the needed investment costs. From the proposed layouts, the costs are calculated. Only more substantial costs are included, such as larger machines and building expansions. For the costs of the machines, suppliers are contacted, and the costs are calculated as realistic as possible. The costs are assumed to include installation. The building expansion is assumed to be made by Martinsons' material, using "industrial hotels", a compartment-based building (Martinsons n.d.-b). The final investment cost is only preliminary.

Martinsons do not calculate the factory profit. Instead, all the costs and profit are handled by the sales department. Martinsons does not know the profit of the specific factory. Therefore, instead of calculating the time to recover the costs, the profit needed for a specific payoff time is calculated. Martinsons uses a payoff time of 5-6 years for more substantial investments. The calculations use a payoff timer for 4, 6, 8, and 10 years.

4.8 Method discussion

In all earlier projects during the studies at LTU, the assignments conducted were in groups of 2-4 students. This project has a smaller team, and it was hard to involve the workers in the system. Therefore, more objective methods were used as subjective methods needs user involvement and several opinions to be fully useful.

An OWAS was used because it has clear instructions on how to use it, without the possibility of making assumptions. It also uses a film of the situation that can be used in other methods, like analysing the flows. Despite being a subjective method, interviews and survey were used. However, being in a system and not speaking to the workers is against the spirit industrial design engineering. The survey was designed to be more objective than most studies are. All the questions were gradable on a scale, which was statistically analysed.

Despite the choice to be objective, several subjective methods have been used. Despite using subjective methods, objective methods were affected by subjective assumption. For example: in the OWAS, it was sometimes difficult to evaluate the position the worker had, or the worker was between two states. In those cases, the worse position was recorded.

In the context immersion, the most significant problem was that visiting the system was only possible when the demand was lower than usual in the shipping. Therefore, the worst-case scenario could not be observed. A lot could have been analysed by it, for example, are there any changes in the routines with removing the remains when the demands are high or low and how they are dealing with them? Instead, the analysis had to rely on the interviews for a realistic picture.

The lacking observation was a result of choosing not to be on site all the time. If the project had been based in Bygdsiljum instead of Luleå, the high demand periods could have been observed without involving the workers. It was decided that the resources at LTU were more important than daily visits to the system.

There was no chance to involve the workers to the desired degree, as the demand is high and Martinsons was behind schedule. Only two workers could participate at the same time in any creative workshop. They did not have the opportunity to remove anyone from the production because Martinsons would they lose productivity.

> We have much overtime already, and I think that no one is interested in any more [to precipitate in a workshop]. …. We are pushed to the limit in the factor and cannot lose any time. I know that your project will save time in the long run, but short term there is no time available [to involve the workers in a workshop] (Jon Martinsons, personal communication, 3 November 2017, translated from Swedish personally)

The small team and lack of feedback from the users resulted in that the concepts were less innovative and unique. A brainstorming requires more than one opinion to be effective. The ideas need to be developed with other people's opinions. In this project, these problems were reduced by having a workshop and using ideas from the workers and also benchmarking.

The grading of the specification was solved with the help of Martinsons' demands but having more opinions would change the pats of the solution by adding more viewpoints of the problem. Martinsons should have been involved in the final specification instead of only the general ideas.

The major problem with subjectivity was in the value matrix. Since the same person created the layouts and valued them, the risk of favouring certain concepts is higher. If more subjective elements had been involved in the evaluation, for example, a discussion regarding the concepts or using an average of several evaluations, they could have been solved. By having the difference between the highest and lowest rank in the evaluation, the risk of favouring any was solved.

5 Context immersion

To understand the problems in the system, one must understand the system. In this chapter, the results of the data gathering are presented. It starts with a description of the production and the flows. Lastly, the work conditions and future of the factory are described.

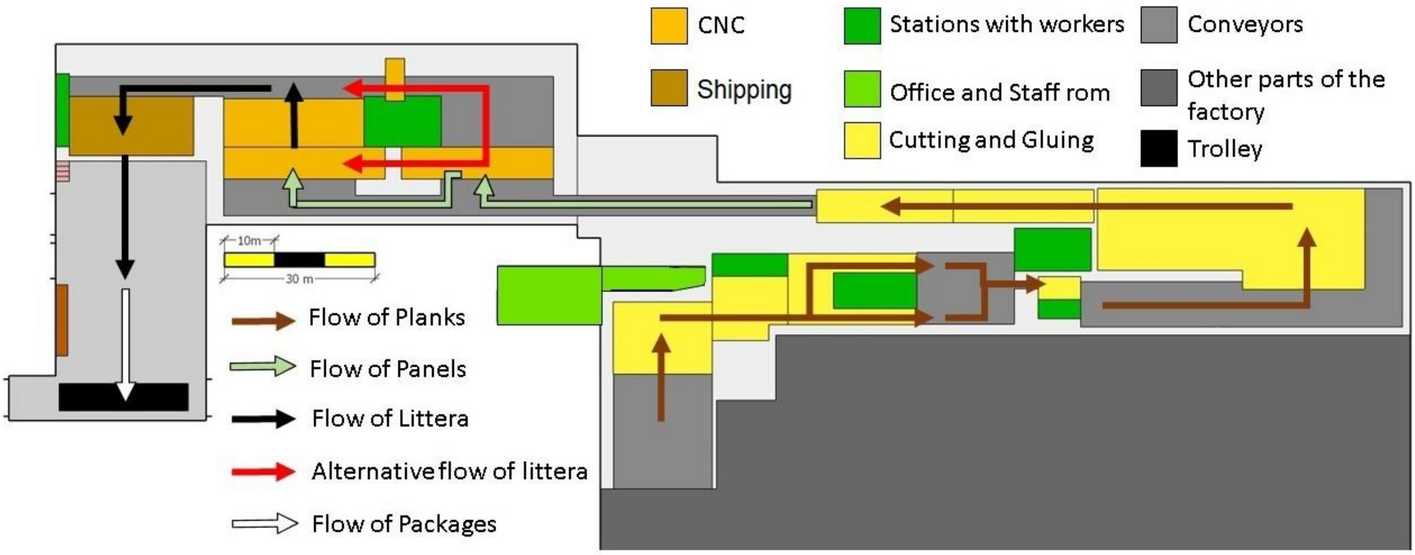

Figure 12: The Layout and Flows in Factory 5

5.1 Factory 5 in Bygdsiljum

Martinsons produces crosslam in factory 5 in Bygdsiljum. In Figure 12 the current layout main flow is presented. The flow consists of planks, glued together and pressed into panels. The panels are then cut to litteras and packed. The system has two side flows in the system, sawdust and cut-outs, but they are explained in detail later in this chapter. The darker grey areas are other parts of the factory. They produce other products and do not affect the production of crosslam. The factory and the production are divided into three parts; gluing, CNC and packing. They are described in the chapter.

5.1.1 Gluing

Planks enter the system, from other parts of the saw, and are inspected visually in order to remove planks that have defects. The planks are joined and cut to get the right lengths. They are then laid in layers in a buffer before being used. The layers are lifted to a table and glue is applied while the machine fetches a new layer. Once all layers are placed and glued, the conveyor moves the panel to a hydraulic press. The panels are pressed for 30 minutes while the glue dries to ensure the quality of the panel. Figure 13 shows the layout of the gluing.

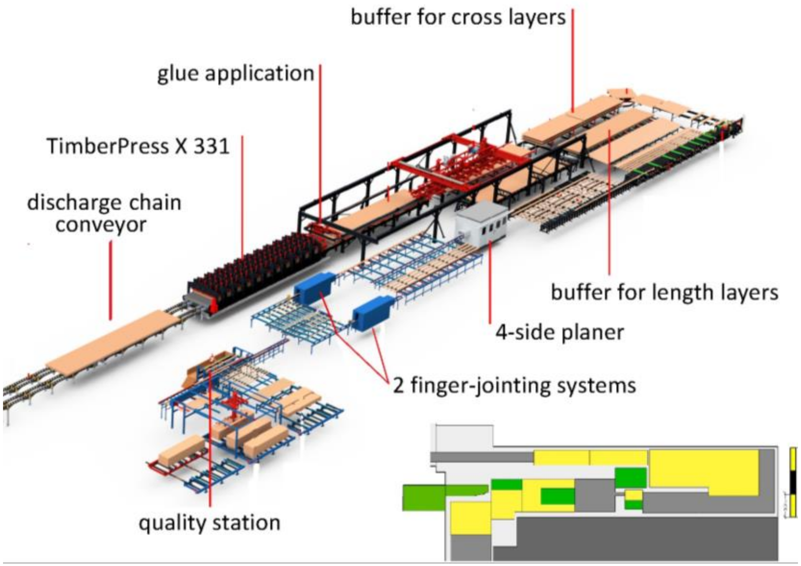

Figure 13: The Gluing Area

5.1.2 CNC

From the press, the edges of the panels are rough, both from uneven planks and excess glue that has dried on the sides of the panels. The panels are moved to the side of the first CNC-machine that cut the edges. Once completed, the panel is placed in a buffer between the CNCs to maintain the order of the panels. The panel can be moved directly to the CNC if the buffer is empty.

The panels that are assigned as visible needs a finer surface compared to normal panels. They are sanded before the second CNC in the sander. Those panels are moved to the side, to the sander. The panel can be turned either in the plunder station or moved back through the sander if the order demands it. The operator must ensure that the panel arrives in the right order at the second CNC.

The second CNC cuts the panels to litteras. Doors, windows, ventilation and other fetchers, like holes for handling, are also cut out at this stage. Some panels are turned to add details on both sides. The operator then checks the dimensions in the plunder station. At the same time, the cut-outs are recovered. They are then sorted and moved separately to the shipping area. Figure 14 shows the layout of the CNC.

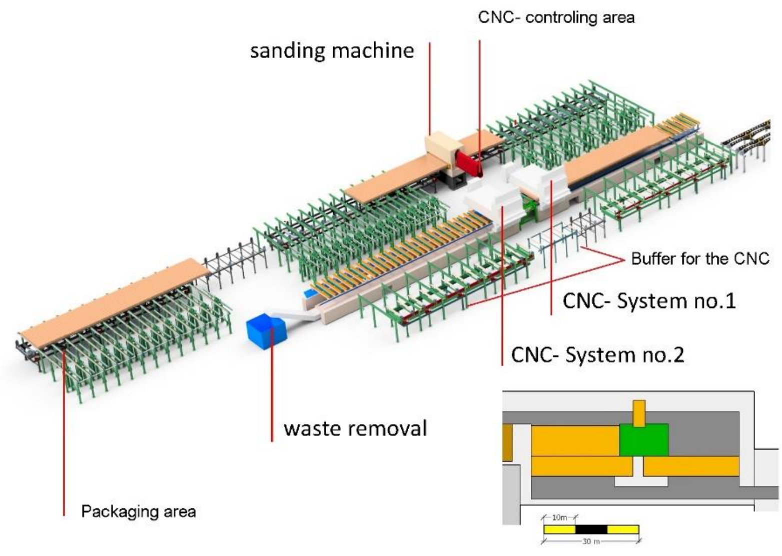

Figure 14: The CNC area

Problems in the CNC

For most panels, the cut is not completely clean, leaving remains on the edges. Most common are “straps”, millimetres thick sheets left by imprecise cutting, but centimetre thick “blocks” are also common. The straps can be removed by hand or with a knife, while the blocks call for larger tools, like a saw, to avoid damaging the littera. Figure 15 illustrates the remains. Lastly, there are cases where the littera have wrong dimensions. The reason for the errors are unknown, but the littera needs to be repaired, either by cutting them or extending the littera to the right dimensions. The adjustments are all made after the CNC in the plunder station or in the shipping area.

Martinsons wants to have the pace being decided by the press. With the current process times in the CNC, there are cases where the CNC has a lower capacity than the press. However, with the considerable variation, it could be possible to have a production plan where panels with a short processing time are paired with one with longer processing time to achieve an average of 30-40 minutes. To achieve this, the buffer before CNC would need

Figure 15: The remains from the CNC Top: Straps, Bottom: blocks

to be larger. However, this would result in a more uneven workload in the shipping area, with long periods with an extremely high pace in the shipping.

The first CNC-machine is not in line with the press. The panels must be moved to the side to have the edges cut. The panel can then be moved through the machine to the second CNC if there are no blocks in the buffer. Otherwise, the newly cut panel must return to the line. The buffer between the press and the CNC can only handle a few panels. If it is full, the CNC can't handle any new panels from the press

The exit for the sander is right at the plunder station. Since there is no syncing between the second CNC and the sander, there is a possibility that they complete their processes at the same time, interrupting each other's flow, although this problem rarely occurs.

5.1.3 Shipping

From the plunder station, the litteras are moved to the sorting area where they are marked and organised before packaging. The litteras are cleaned from sawdust and remains before they are lifted to the floor. Figure 16 presents the layout of the shipping.

When the litteras are ready, the littera is moved to the floor by an overhead crane, as the sorting area is positioned higher than the packaging area. If a littera needs a significant adjustment, it is done in the repair station, called EBH. Before placing the first littera on the station, a plastic sheet is placed on the station by hand. They are used later for packing material. Usually, tables or trestles are used to pack the litteras, but to save time the litteras can be packed directly on the floor. To be able to move the rolls with the sheet, the rolls are stored on a hand-pulled wagon. The wagon also acts as storage for some tools. After attaching the first sheet, one more sheet is placed over the package, covering it completely, and attached with packaging tape. Lastly, edge protections and labels are attached to protect the edges when lifting the litteras and to identify the package.

Several litteras, especially those used for walls, have holes for doors and windows. In other packages, the bottom littera is smaller than the rest or have a weird shape. These weaker areas can cause damages on the littera if lifted incorrectly. These areas are marked with black/yellow tape to avoid damages on the litteras. Any holes in the top littera have holes the package is also marked to avoid accidents if anyone should step on it.

On many construction sites space is limited, especially in cities, so the orders are packed in usage order for the customer. Therefore, the first littera produced and packed is the last one the customer needs and vice versa for the last littera produced. It creates problems when one littera, of a different thickness compared to the others, arrives late to the shipping. One order can be divided into several packages, depending on the size of the order and litteras, and for extra flexibility in the production. When the packet is ready for shipping, the crane lifts the package to a trolley that is pulled out to the yard by a tractor and sorted before transportation.

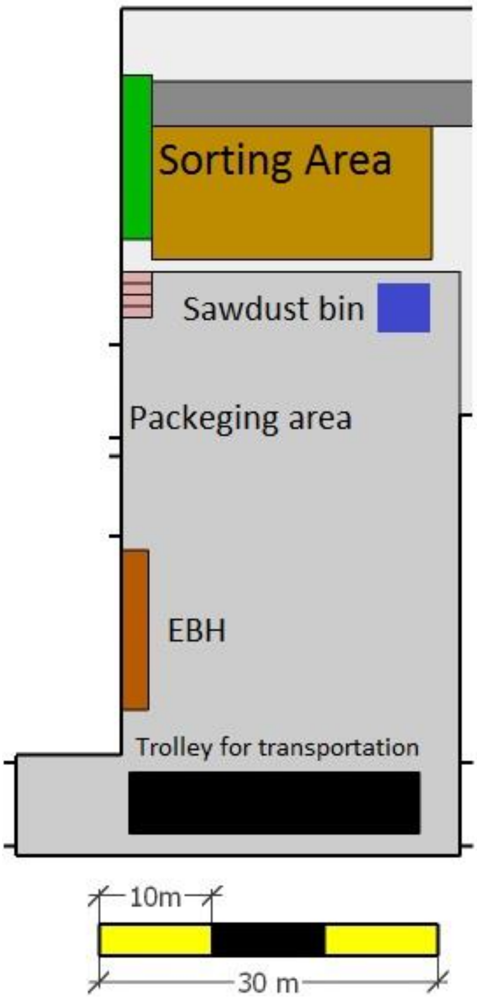

Figure 16: The layout in the shipping area

Problems in the shipping

The current packing area is provisionally an empty room. The original plan for the packaging was changed to fit reality. However, the shipping did not receive changes with the new plan, and any changes that happen take time. For example, the packaging area did not have tables to pack on until the end of October 2017. *"it took almost six months to install those brakes [for the wagon that holds the sheets], and only now have we received actual tables"*. (worker in the shipping area, personal communication). The slow improvement of the area has, with the unpopular environment and lower capacity compared to another part of the saw, given this area a bad reputation among other parts of Martinsons.

The production order

The production order in the press is optimised to the gluing and storage has planks for panels with the same thicknesses. To have a mixed order, the storage in the quality area would have to be larger.

It causes problems when combining it with the need to pack all the litteras in the correct order. It results in problems where a package consists of serval thicknesses. If a package has several thicknesses, the packages are forced to wait for the last littera for a long time. It causes days with several "almost-ready" packages, missing only one littera that is produced later in the day. They are using up space that could be used for other packages, resulting in more handling and lifting with the crane. The uneven workload causes periods where the workers have nothing to do but wait for the last littera for several packages. When the litteras arrives, the workers are struggling to keep the pace as many packages receive the last littera at the same time. Figure 17 shows how the shipping can look like during a normal day with many packages waiting for the last littera.

Material handling

The workers in the packing area do not like the overhead crane or trolley that they are using. It takes time to prepare the lifting, especially when using straps. It takes time to attach them, and they allow littera to swing during the lifting. If the litteras do not arrive in an optimal order, the

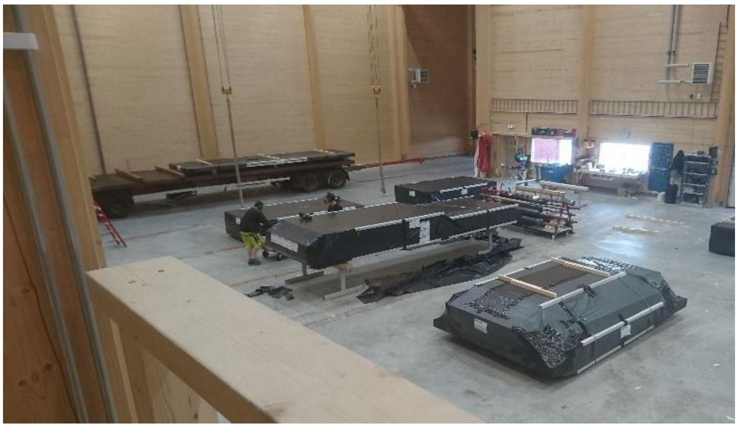

Figure 17: The shipping during a crowded day

workers are required to relift some litteras to make space in the parking area.

The crane is required in the current system, as the sorting area is located above the floor. The litteras are hard to turn 90° because of there length. Therefore, the conveyors will use more space in the shipping compared to other parts. The conveyor would need to be at least 16 m wide to be able to transport all sizes. If the litteras could be turned, only 3 m wide conveyors would be needed, something that Martinsons has today. However, the turning would risk damaging the workers and the litteras.

When the trolley is full, the tractor is called to remove the trolley. The trolley can be changed quickly if the tractor is available directly. Most of the times the tractor is busy and needs time to arrive, delaying the change. When the trolley is full, the crane cant moves the packages from the stations and they are left on the floor, using up the floor space longer than necessary. Worst case scenario, litteras fill the sorting area and space between the shipping and the CNC and cause a bottleneck.

Packaging

The package is currently done with two sheets of plastic. This method is slow and needs to be improved to maintain pace in the factory. According to the workers, with the current demand, the pace cannot be maintained with only two workers. The individual order of the litteras in the package is causing problems, as stated earlier.

The laying packages are causing problems in the handling because of the packaging order. Sometimes smaller, irregularly shaped litteras or litteras with holes are placed under larger more uniformed litteras. When lifting these packages, special care must be taken to avoid damaging the litteras. If the litteras were standing while packaging, the lifting forces would be applied on the edges of the litteras where they are stronger, compared to the weaker sides when packaging today with the litteras laying down. The future predictions are that the demand for walls will increase.

5.2 OTHER IMPORTANT FLOWS

There are two flows in the shipping apart from the littera; sawdust and remains, and cut-outs. The flow of sawdust and remains, henceforward called sawdust, is a waste with no value caused by the machines. Cut-outs are not waste as they have some value because they can be reused or sold by themselves. Figure 18 presents the two side flows.

5.2.1 Sawdust

Inside the CNC-machine, there is a transporting belt that moves the dust to the bin in the packaging area. 1-2 times/shift a tractor is ordered to empty the bin. Precisely, the bin was removed with the crane. To save time for the crane, it was changed to the tractor. As a result, the space equivalent to two packing stations cannot be used for packaging. The stations would be in the way for the tractor.

The belt in the CNC does not collect all the sawdust, some fall to the sides. The dust and blocks that fall down the side of the machine not have a conveyer and build up next to the machine. Some worker cleans it during the weekends to avoid interrupting the production and to avoid accidents. Some blocks on the side are so large that they need to be cut to handle.

Lastly, the sawdust left on the littera is blown away at the sorting area. The sawdust is collected on the floor under the sorting area. It does not affect the production, but it needs to be collected from time to time.

5.2.2 Cut-outs

In the plunder station, the cut-outs are recovered and placed on a pallet. When the pallet is full, it is moved to the sorting area and

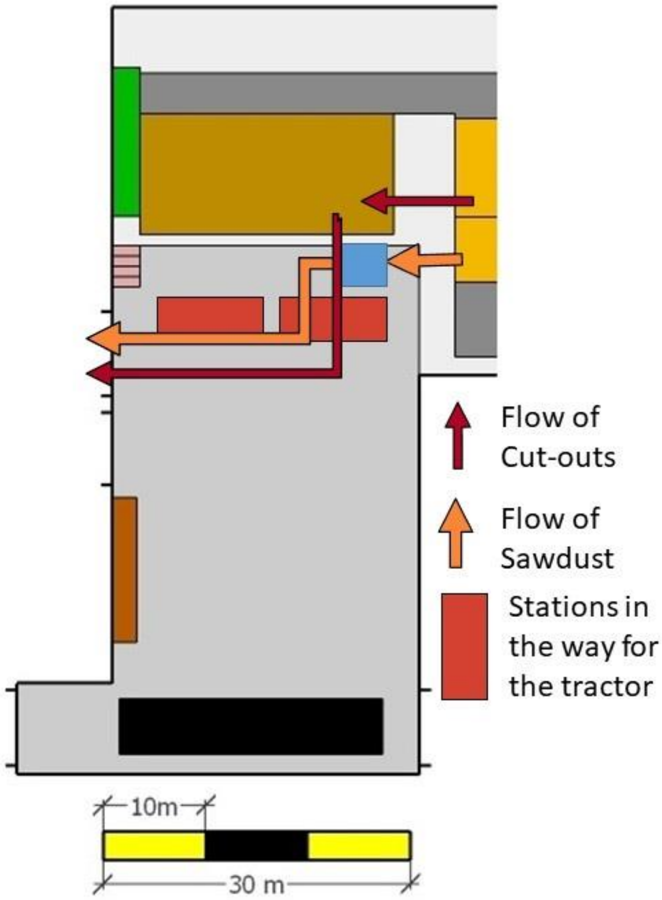

Figure 18: Current flows of Sawdust and Cut-outs

lifted to the floor. Compared to the litteras, only one sheet is used to pack the cut-outs. The pallet is collected and moved to storage before being sold separately. Small or irregular shaped cut-outs are not useful and thrown in the blue bin with the sawdust and later reduced to wooden chips.

The transportation of the cut-outs is performed by the same crane as the litteras. It creates more work in the packaging area and takes time from the overhead crane. The workers wish to focus on the littera in the shipping area.

5.3 THE MACHINERY

The following machinery is available in the system today:

- 1 Quality station for the planks
- 2 Cutting and joining stations
- 1 Planner
- A Table for constructing the panels
- 1 Timber press machine
- 2 CNC machines
- 1 Wide-belt sander
- 2 Overhead cranes on the same track
- 1 Overhead crane in the "plunder station" to remove cut-outs
- Trolley for removing the packages
- Conveyor for moving the panels
- Sawdust transporting belt and a bin to store it

There are more tools available. They are of little or no importance when looking at the entire system. The conveyor has three turning tables to flip the panels: before the sander, in the plunder station and the sorting area. The latter is rarely used compared to the other two.

5.4 Relations between the stations

The only dangerous relation in the shipping is the one between the sawdust and the computers, as the dust can damage the computers. One idea, from a worker, was to have an office in the shipping, where the workers can handle order planning and similar tasks without the dust. The handling of sawdust and cut-outs are all unwanted in the shipping area as they are using up space and interrupt the more critical flow of littera.

The stations for the packaging wall and floor littera need to be near the package removal, EBH and to have access to tools. As a result, the stations can be placed next to each other. The workstations in the packaging require access to the crane, for lifting, the material for packaging, label printer, and EBH. The CNC only needs access to the waste handling, plunder station, quality station and cut-out handling. Workers wish to have a tablet too check the dimensions when checking the cutting instead of having to use a clipboard. Appendix 3 presents the full proximity analysis.

5.5 Routines

The routines are summarised in Figure 19. The first thing the worker does when a littera arrives at the sorting area is to check the packing list to see which one it is. The worker prints a tag that is attached to the side of the littera. Any leftovers from the CNC are removed and any parts that risk damage during the lifting, for example window and doors on the edge of the littera, are reinforced by a small panel. If there is time and the litteras arrives in the correct order, several litteras are sorted and lifted at the same time. Usually, the litteras are moved one by one because they do not arrive in the correct order for the packages. Time can be saved for the crane by lifting serval at once. Planks are placed between the litteras so that there is space for a truck or to fasten slings to lift an individual littera at the at the customer's construction site.

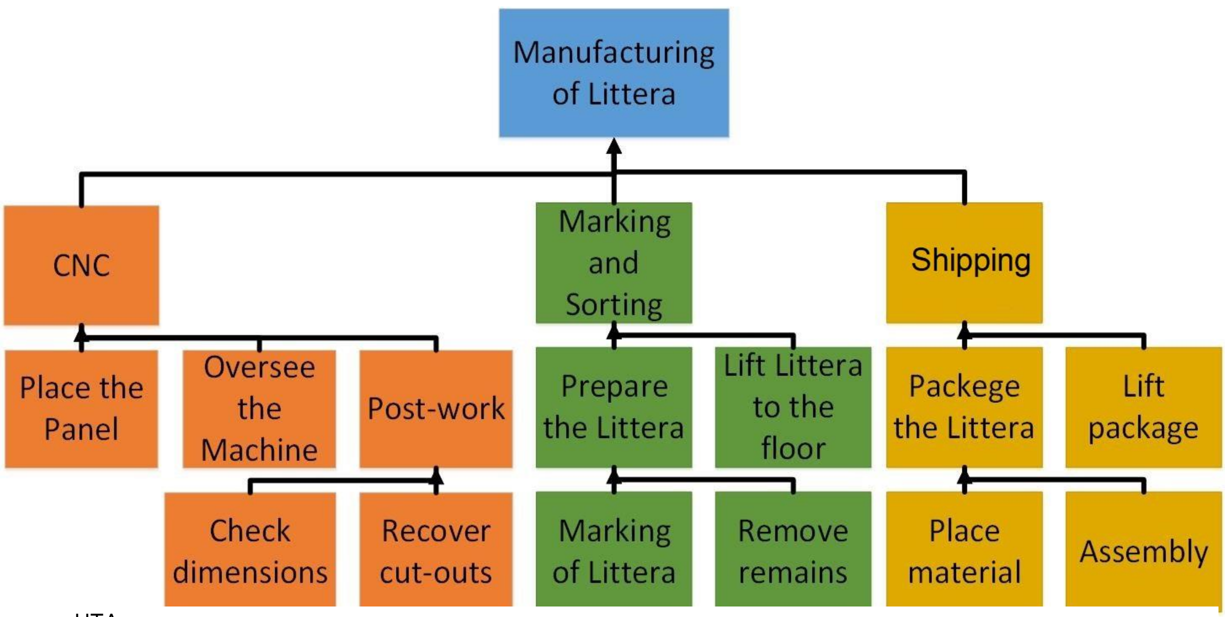

Figure 19: HTA

The plastic sheet is placed first when starting a new package. The worker adjusts the sheet when placing the first littera by stretching it to ensure that the sheet sticks to the littera. The rest of the litteras for the are placed package with sticks between them, to make space to fit lifting tools at the customer. If the littera needs repairs, the littera is moved to the EBH. The first sheet is attached with small nails. When all litteras have been placed on the station, the top sheet is placed and attached. Any areas with windows and other weakness are marked with tape to prevent damage when lifting. Covers are placed and fastened to protect the edges. Finally, a tag is attached, and the packages are moved to the trolley to be moved outside.

5.6 Work conditions

There are nine workers on each shift, with two shift each day except Friday. The work in the gluing and CNC is mostly automatic with the worker overseeing the machines and ensuring that they are working. The packing is more “hands-on” in its work. The CNC operator runs the CNC machine and removes the blocks for windows, doors and remains, that were not cut away entirely, but most commonly it is removed in the packaging. In the packaging area, one worker marks the litteras and attaches them to an overhead crane while the other two package the orders. Figure 20 presents where the workers are situated and the central pathways marked out.

5.6.1 Physical work

There are two stairs on the floor that the workers use several times per day. The steps of the stairs are narrow and may be slippery due to the sawdust.

The temperature in the shipping area is usually 20C°. The problem occurs when the gate is opened for the tractor to empty the trolley. It happens several times a day, depending on the sizes of the packages, and causes a wind tunnel through the factory, especially in the CNC area. The gate can be open for several minutes each time. The temperature in the shipping area can drop significantly. The temperature dropped from 20 to 16 C° (without taking the effect of the wind into account) when the outside temperature was around 0, with the gate open for a few minutes. The workers describe the wind speed as "significant to heavy, especially in the CNC". The workers in the CNC and shipping area describe the climate as cold, including the draught. The problems are more extensive during winter when the weather outside is colder.

Both the sorting area and the shipping require much walking around in the station. The distance is long because of the sizes of the litteras. To get to the sorting area from the floor, the worker must go up a stair. All workers are complaining about it, mainly when operating the crane. The situation in the packing area includes a lot of extreme positions while packaging. In the sorting, the workers are required to jump up and in down holes to remove remains.

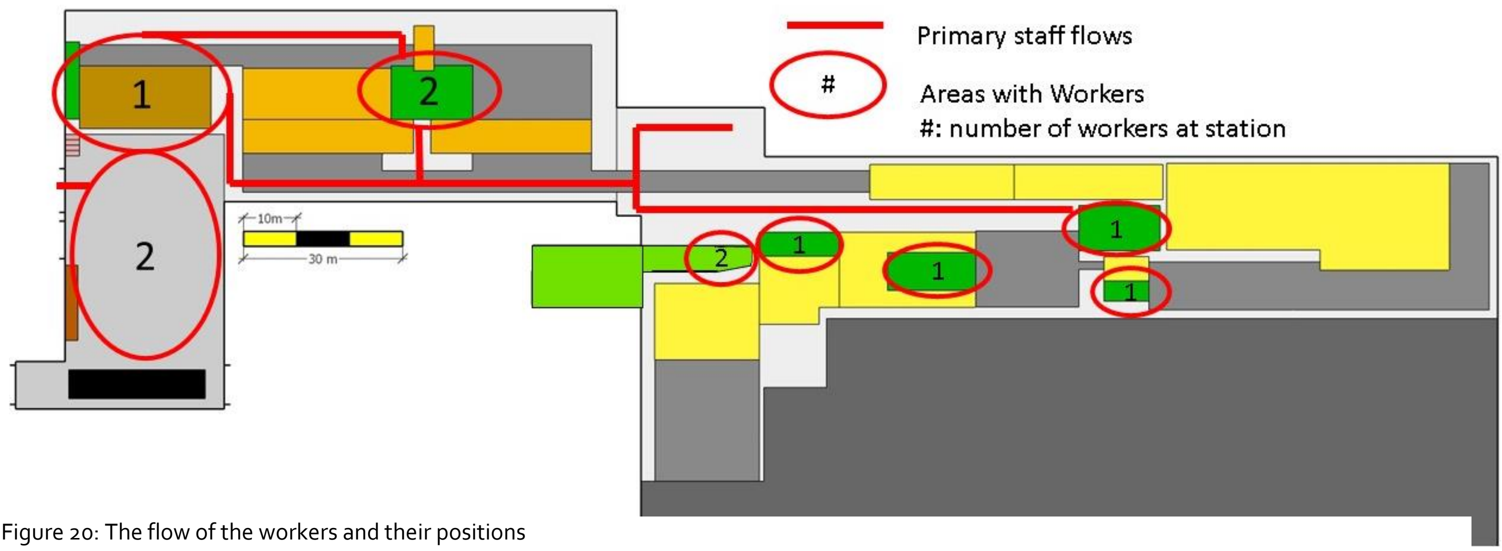

Figure 20: The flow of the workers and their positions

5.6.2 Psychosocial environment

All the workers wear ear protection with a microphone to communicate with other people in the system. The gluing area has some situations where the worker is alone and isolated in the workplace with little social interaction. However, the CNC and shipping require more teamwork, preventing someone from working alone for extended periods of time. The workers in the shipping can communicate with the microphone in their headsets to organise their work. No major social conflicts were observed. Everyone is equal in the workplace and does the same assignments, but there is one worker who has more experience than the rest and has become the unofficial leader.

Most of the time the workers are struggling with meeting the demands placed on them by the rest of the system. A lot depends on the shipping, as it is the last station of the production. Because of the sizes of products and the extra work needed, the risks of queuing are high. They have to move the litteras to the floor as quickly as possible to make space for new litteras from the CNC. Even though delays are common, like when there is a mistake on the packing list, and many adjustments are required, the problems can easily be solved. However, the small interruptions cause larger time losses during an entire day. In the interviews, the workers described that the average demand is close to the maximum capacity in the shipping, which supports this opinion.

5.7 Future challenges

The current plan for the production of crosslam is to ensure that the new system is working at 100% of its capacity. Other aspects in the future will affect the system. Based on the analysis of the current stage two main problem areas have been discovered.

5.7.1 Lack of throughput

Martinsons has problems to achieve the planned production volumes. These problems are causing stops in the factory that cost money. Martinsons have estimated that each hour that the system is standing still costs 10,000 SEK.

Two companies are building factories to produce crosslam in Sweden that will be ready in 2020. The market will change, and Martinsons may lose customers. The lead times must be reduced to ensure that Martinsons can supply the demands. More producers will also make the future demands of crosslam higher.

5.7.2 Working conditions

The conditions for the workers in the packaging are not sustainable. It has risks for MSD, which must be solved both for an ethical reason and to improve the capacity and to improve the reputation of the shipping.

6 Analysis of the current state

The production has several problems. Some are only minor disturbances, but some problems have larger effects on the packaging and flows. Problems exist in most sections. In this chapter, the problems are described in the different sections. Lastly, an ETH is presented, which summarises the problems.

6.1 Capacity

The capacity of the system is analysed from two views: the actual production and the theoretical production based on processing times. Martinsons does not want to reveal the actual numbers. Therefore, actual capacity is presented as the changes from the planned volume in percent (%). The data consists of 39 weeks of production.

6.1.1 Actual

The new system started its production in week 1 of 2017 with a start-up period. The system was fully active at the end of May 2017 after increasing the production monthly. Since then the system has been active for 18 weeks. This analysis ignores the weeks without full production. During four separate weeks, the weekly production target was reached or exceeded (22% of the total). The average production was 77% of the planned volume each week. On the whole year, Martinsons is behind by 23% compared to planned volumes.

6.1.2 Theoretical

Each process has been analysed and compared to each other. On an average, the daily target is to produce 19 panels.

The press is the only machine with a fixed time. It takes 38 minutes: 8 minutes to set-up and 30 minutes drying, to make one panel, no matter the size. Martinsons wants the press to set the pace for the entire system. The processing time in the first CNC depends on the size of the panel. It takes between 5-6 minutes to cut the edges of a panel. The first CNC is rarely a bottleneck. The processing time in the sander depends on the length of the panel, and if both sides need sanding. The time is between 3-4 minutes, as the machine has a speed of 5m/min. If both sides need sanding, the processing time is doubled and time for turning is added. The sander is not a bottleneck by itself as it has short processing time and is only used for a few panels each week. The flow around it can create more problems and handling time.

One of the significant sales factors for Martinsons crosslam is the high prefabrication with doors, windows, and space for piping and so on, adding many variations which cause the processing time to vary a lot from one panel to another. The more complex cutting order, the longer processing time. Figure 21 presents the simulated processing times, not including the setup, for 183 panels. The average simulated time is around 1-20 minutes. Please note that the times are the ideal times, with perfect tools and no problem in the processing. The actual times diverge a lot from the simulated because of mura, like tools that are dull, the speeds for the tools are slower due to frictions, and other factors.

According to the CNC operators and cad drawer, the actual time can vary from 2 minutes to 3 hours, with an average of 30-40 minutes. The CNC has other time losses: tools to replace with sharp tools, dimensions that need checking, and other time-wasting activities. All these time losses can cause the CNC to, during a day with many problems, lose up to ¼ of the total time.

Once in the shipping area, the processing times are no longer on panels but in litteras or packages. One variation is how much extra work a littera needs, like removing remains and sawdust and attaching supports for the lifting. To save time in the lifting with the crane the workers are trying to organise the packages in the sorting area so that the crane lifts an entire package at the same time. The workers have only time for it when the supply of new litteras from the CNC is lower than usual.

There can sometimes be more extreme faults. For example, the dimensions can be wrong, or one panel can need smoothing. If the littera is too long, it is cut, but if it is too short material must be requested to repair it. The delivery times can be long as the other factory has its production plan. Sometimes, a sanded littera may need extra sanding. The case may be that someone stepped on the littera, leaving a mark. Sometimes an entire panel may need to be smoothed again. The workers use hand-held tools to do the extra sanding. On average, one littera needs additional repairs every day.

The two major operations that take time on the floor are the packaging and lifting of litteras and packages. Each lift needs a setup by attaching the lifting device. Therefore, workers attempt to sort the litteras in the sorting area and lift several at once to save time. It depends on what the order is and the result from the CNC. The workers have two kinds of lifting devices, the first one is attached to a hole and locks itself in place. While the other one, slings, is used when they cannot drill in the littera. It becomes a problem when there are many litteras at the same time.

The packaging is done manually by the workers. Due to the size of the packages, the worker must go around it while placing the plastic sheet, attaching protections for the edges and straps to keep them together. The marking of weaknesses also adds extra time to the packaging.

Sometimes, it can take time for all the litteras of a package to arrive. It happens when a package has several different thicknesses on the litteras. The cause of this problem is in the gluing. The storage is easier if the planks are of the same class, compared to having a mix of them. The results are that the package must wait for the last one before being packed, using up space in the packaging area as it waits. It results in days where there is almost no activity in the shipping area, to then be stressful when the last littera for several packages arrive at the same time.

Assuming that there are no problems with the new littera arriving at a regular interval, marking and packaging should not take long. The packaging takes around 10-15 minutes once the litteras are all placed on the table, assuming there are no weaknesses. It takes more time if the litteras are lifted one at the time and if there is a weakness. At usual demands, the workers are struggling with keeping the pace, mainly because of the crane.

6.1.3 Conclusion

Both the first CNC and sander have a higher capacity than the press. The flow and layout cause no problems at these stations. The second CNC is struggling to be in phase with the press. It has a more substantial variation in its processing time and has more time wasted. When the processing times are longer, the buffer between the CNC and press risks becoming full, forcing the press to stop. Lastly, the major problem in the shipping is the crane. The crane is a bottleneck, and no one likes it. The transports with the trolley are also time-consuming and create new problems. Table 4 presents the cycle times and the theoretical maximum capacity for the press, CNCs and sander in panels/day.

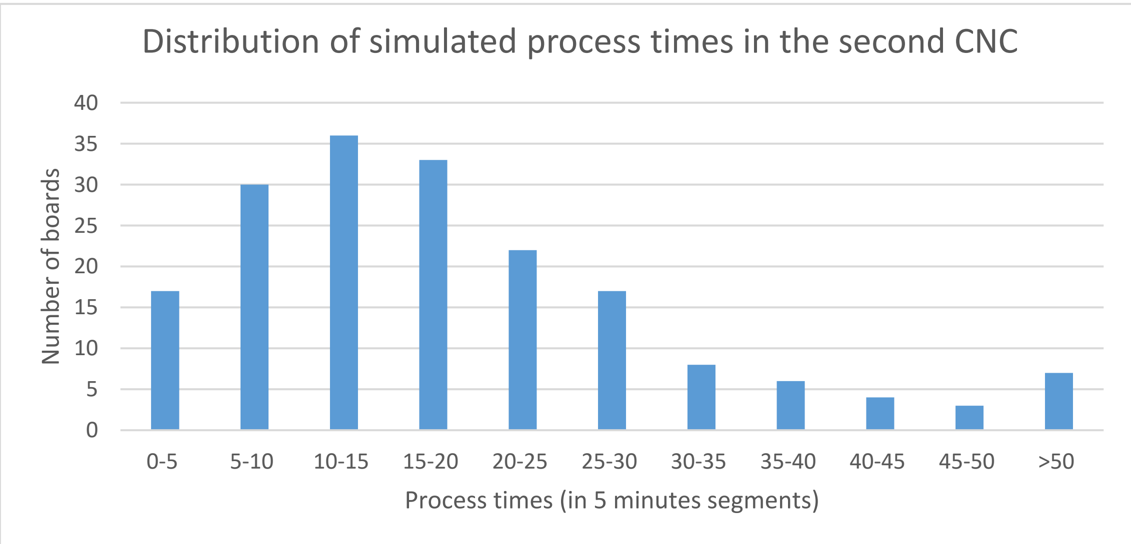

Figure 21: Distribution of processing times in the second CNC

6.1.4 Summarised

The current production has many variations that cause unevenness in the production. The theoretical capacity is in level with the press and the daily demands, but the actual capacity is behind. The varying process times in the second CNC and the uneven workloads are the main factors behind the difference.

Balancing the system against the press pace is hard. Martinsons is planning on changing the orders. Today, a large part of the production are houses, with doors and windows. Martinsons is planning to change it to 50% houses and 50% industry, with fewer details used. As a result, more packages will consist of walls, compared to floors and roofs. Martinsons is also working to change the planning to give the shipping more flexibility in their work and to ensure that the litteras for one package arrive after each other.

Table 4: Theoretical Capacity for one day

Daily demand	19 panels	
	Cycle time /panel	***Maximum daily production***
Press	38 min	22 panels
CNC #1	*5-6 min*	140 panels
Sander	3-4 minutes/sides +turning time if needed	84 panels
CNC #2 (average)	30-40 minutes	28-21 panels
CNC #2 (with time loses)		21-ca 16 panels

6.2 Ergonomic

The ergonomic analysis consists of two parts; the first describes the OWAS on the sorting and packaging and the second describes the survey.

6.2.1 OWAS

The analysed period in the sorting area had a lower demand than average, so during the film the worker was standing around and talking with his co-worker and organising the workplace, meaning the analysis seems better than reality. The positions and the distribution of the specific body parts can be found in Appendix 3 and 4. Appendix 3 concerns the sorting area while Appendix 4 concerns the packaging.

The OWAS for the sorting area provided 58 positions. Most of the work in the sorting area is operating the crane and walking around; it is easy to have the back upright during that part. The only time with a bent back is during the beginning of the cycle when the worker is removing remains, but at that time the back is bent a lot. The waste removal is the most dangerous activity in the sorting. As a lot of the work is on the floor or in the air, the neck is in a bent position almost half of the time. The final recommendation is that no particular action is necessary. Even though, the positions with the more demanding positions need deeper analysis on the next planned review of work methods. Many times, the worker has to go upside down to have a better position to remove the remains. It takes much energy, and the OWAS does not address it. Figure 22 shows the distribution of the risks based on activity.

In the packaging, 87 positions were analysed. The OWAS found that, during the analysed time, the back was in a bent position half of the time. One or both arms were over the shoulders roughly 1/3 of the time. The worker was mostly standing on two legs or walking, roughly ¾ of the total time. The recommendation for this section is to take corrective action during the next regular review of work methods. The situation has become better during the project.

According to the workers, there was more bending the back without the trestles. Nowadays, the OWAS can see that there are fewer bends as the packages are higher, but there is more work above the shoulders and with a twisted back. One observed risk area is when the cover sheet is attached. There, it is a combination of bent back and demanding position with a bent neck and arms above the shoulders. The situation that has the most significant risk for MSD is when the worker is attaching the cover sheet. The sheet attaching is the most dangerous because the back, neck and shoulders are in damaging positions. Figure 23 shows the distribution of the risks based on activity for the packaging

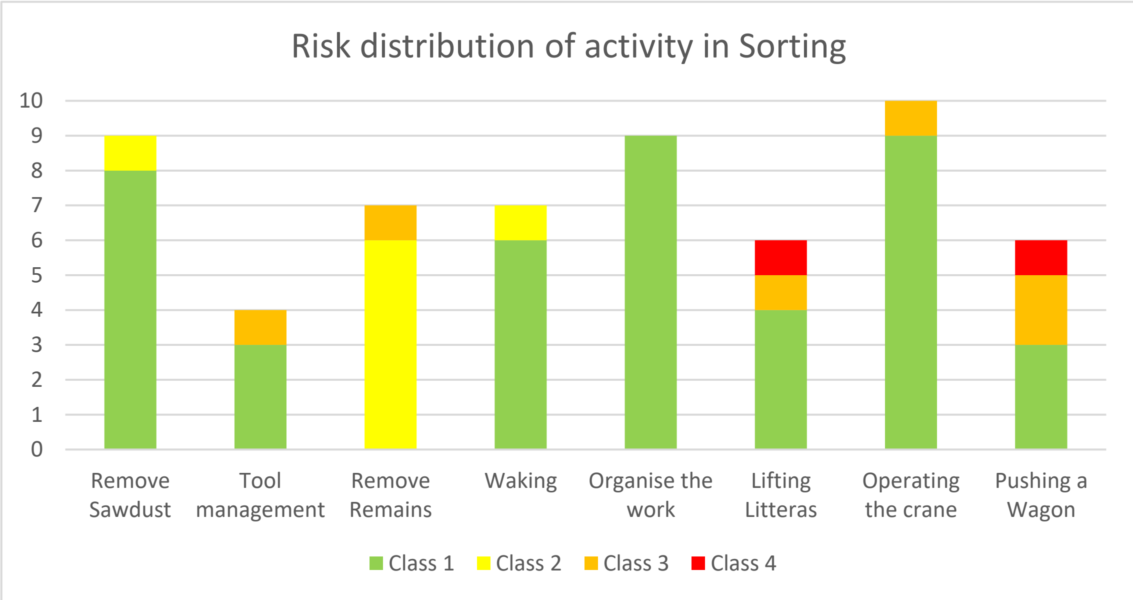

Figure 23: Risk distribution in the Sorting

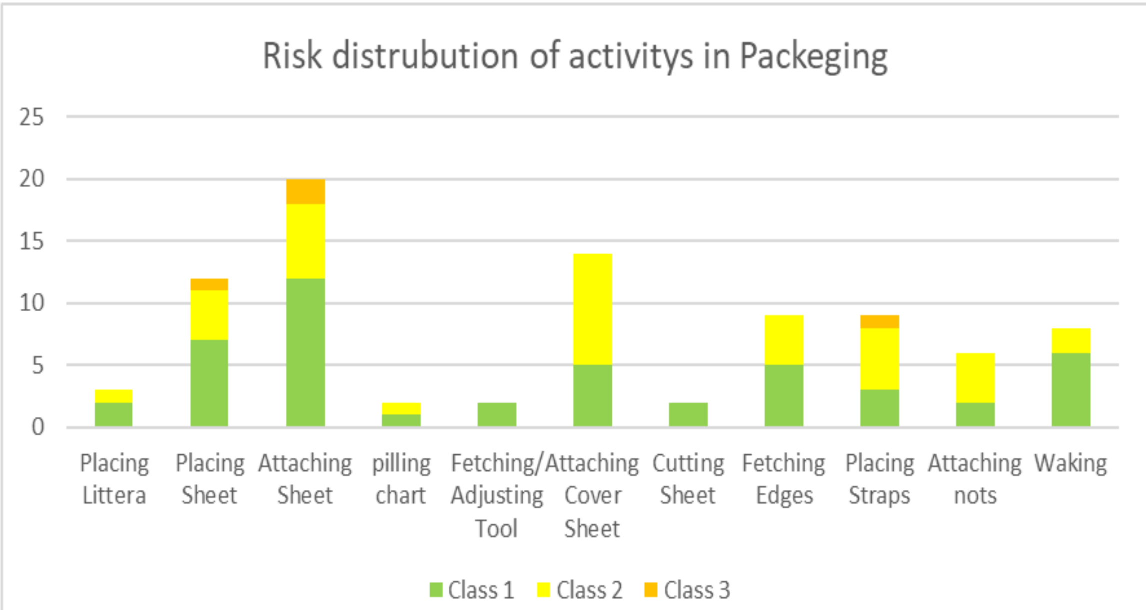

Figure 22: Risk distribution of the Packaging area

When summarising the entire shipping area, with the assumption that the workers are each spending 2/3 of the day packaging, the total result is that almost 60% of the positions are class 1. However, there are many positions in class 2, 34%, meaning that there are some risks for MSD. The final recommendation is to adjust the situation at the next regular review of work methods. Figure 24 shows the final summary of the full shipping area.

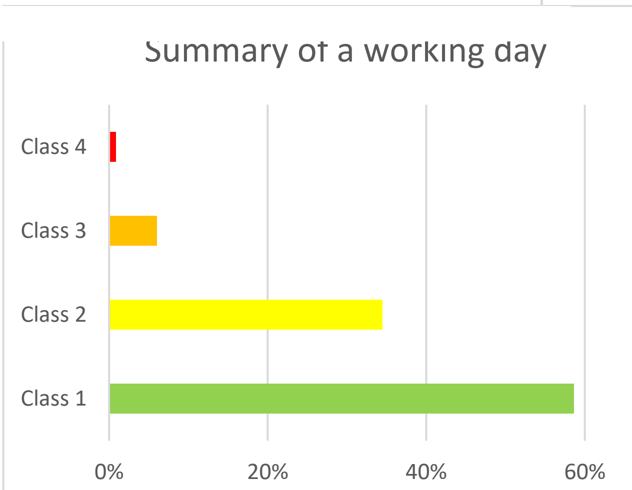

Figure 24: Summary of the entire Shipping area

6.2.2 Survey

Ten people participated in the survey. Three of them were in the gluing, one in the CNC, three in the shipping and one were both in the CNC and shipping. The people working in the shipping has been working the shortest experience of the system, 4.7 months.

The demands are high on the workers in all parts. CNC and shipping are above the average, but not by that much. The workers feel that, compared to the demands, they are in control. However, the freedom and the challenge of the work are low. The social relations have all a high score, with most of the relations being an 8.9 or 10. The situation is, according to the demand-control model, strained.

All workers can take a short break if needed. The only station where a worker is alone is CNC during lunch. However, during the observations, based on the observations, it was assumed that the gluing has more work alone than the rest of the factory, and the CNC and shipping would never work alone. It may have been a misunderstanding of what "working alone" means.

Because of the demands, the pressure to work quickly is high, and the workers feel that they are required to work in dangerous positions. The levels of the different positions are mostly the same. The energy demands are not too high or low, but there is a lot of walking and standing in the packaging, which can cause MSD (Winkel 1989).

The workers are working with a bent back, under the knees, and crouching for long times in the packaging, which is supported by the OWAS. The gluing is the safest position with few damaging positions. Everyone thinks that the noise is high and they can hear the noise even with the ear protection. However, it is more important that the noise levels in the ears are low, not that there is no sound. Complete sound isolation can increase the risk of accidents.

Half of the workers are reporting pains in the body that the workers believe to be caused by the work. The pains are most likely caused by walking on concrete, heavy lifting and working outside normal reach. The pains are most common in the shoulders and back, with some pains in the knee and foot. Most of the surveys said that they had not received instructions on how to work while maintaining a good position, and no one had received help with the problems. Both of these points are worrying as it means that the workers may have taught themselves damaging routines, which improve the speed in the packaging but cause risks of MSD.

The employer is required to inform the workers on how to perform the work safely (AFS 2012:2 9§), and any damages need addressing as quickly as possible (AFS 1994:1), both from an ethical view and ergonomic to avoid worsening the problems.

6.2.3 Conclusion

When changing the trolley, the gate is opened, and the temperature drops because of the difference between the temperature indoors and outdoors. The temperature problems are of course more significant during winter. The draught caused by the shape of the CNC area makes the problem more significant there, and they are affected several times a day. The shipping has some risks for stress, as the demands on the workers are high and the freedom in work is low. The saving grace is the high social support and that the workers feel that they are in control.

The packaging has some of the worst working positions in the system, with many bends and raised shoulders, causing risks for MSD. The situation is improving slowly by adding more tools to help in the packaging. The packaging has a lot of walking and climbing in holes. These activities consume much energy and create pulses of high loads on the legs and knees.

6.3 Conclusion of problems

The problems are a result of lacking organisation and unreliable information. As a result, there are many unnecessary activities that lower the capacity of the shipping. The shipping is not optimised for the packaging and any changes suggestions by the workers are implemented slowly. To match the optimal staffing, two workers in the shipping, the flow and routines must be improved. Table 5 presents the problems that affect the capacity and ergonomic. The problems are divided into the different sections that are connected to the problems.

Table 5: ETA, problems and their cases

Area	*Problem*	*Case*	*Sub-case*
CNC	*Unreliable cutting*	Wrong in the cutting	Not correct position
			Fault between file and saw
		Wrong in the planning	
	Time in cutting	No-optimal cutting order	
		Complicated cutting	High prefabrication degree
Packing	*Extra work*	No-optimal planning	Tacks time for some litteras to arrive
		Lots of small adjustments	Unreliable cutting
		Wasn't done at the CNC	No time available
			Wasn't possible
		Too little information on the packing list	Bad planning
			No communication with planning
		Provisional layout	
	Long packaging time	Lifts with the overhead crane	Mounting of lifting devices takes time
			Lifts of cut-outs
		Extra work	
		The trolley solution	Has to wait for the tractor
	Ergonomic problems	Many extras positions	
		Stress	High demands and no challenge
		The temperature in the room	The gate is opened, causing a draught
		Bad reputation for the shipping	
Flow	*Flow of cut-outs*	Hinders the flow of littera	
	Flow of sawdust	CNC does not handle all of it	
		Uses space in the packaging	Removed by tractor
	Flow of littera	Not enough space between the press and CNC	
		Complex flows around the CNC	
		Much lifting required	

7 Specification of requirements

The following section presents the demands placed by Martinsons on the solution. They are later interpreted to what they mean for the solution and graded on how important they are compared to each other.

7.1 Demands form Martinsons

In the following section, the primary demands from Martinsons are presented and described. They are the foundation for the specification

Eliminate wasted time in extra work and lifts

Much unnecessary work occurs in the shipping area, wasting time, and the system with the overhead crane requires much time. If possible, no littera should be re-lifted.

Optimise the use of space in the packaging area

Ensure that as many packages as possible can be worked on at the same time without hindering the packaging of them.

Improve the recovery of space in the packaging area

Ensure that the recovery of space is as quick as possible in the packaging area so that there are no completed packages that use up space.

Improve the work environment with regards to ergonomics and temperature

Prevent risks to the wellbeing of the workers caused by the temperature, working posture and physical health.

Improve the flow of littera, sawdust, cut-outs

Make sure that the flows are not crossing and hindering each other and make it easier to fulfil the capacity needed.

Improve the work with the adjustments

Martinson is working to improve the CNC to lower the need for adjustments after the CNC. The faults caused by the CNC result in extra work in the shipping and waste time. By lowering the wasted time, the capacity will improve. The improvement of the CNC is outside the scope of the project, so the effect can not be taken for granted. The final solution needs work even if the problems in the CNC remain.

Flexibility in the planning in the production

The order planning has some problems today with some littera arriving later than the rest, which results in more problems with the organisation in the shipping. Martinsons is also working on this. However, as with the CNC, the result cannot be taken for granted. The final solution needs work even if the production order is not optimal.

Minimise effects of bottlenecks

The approximate cost for one hour of standing still in the system is 10,000 SEK. Any bottleneck costs much money and risks Martinsons' deliveries to the customers.

Improve the packaging of walls

Walls require extra care in the packaging and handling in the current system, because of weaker areas, caused by the windows and doors. With the future demand for more walls, the needs of the packaging will increase.

7.2 Specification of the solution

The specification is organised into four sections: eliminate waste, work environment, flows and layout. Table 6 presents the grading of each specification. It includes a brief description of how it is defined. The needs are a combination of demands from Martinsons and other aspects to ensure that the results are within industrial design engineering.

7.2.1 Motivation for the grading

The most important demands are minimising required lifting, improving the handling of littera and packages, and making the recovery of space faster and easier. In the shipping, these aspects are critical to have a high throughput.

The aspects with rank 2, are all ether not fully expressed demands from Martinsons or a continuation of a rank 3 demand, like the flow of cut-outs are connected to the flow of littera.

The rank 1 demands are demands that would not differ from each solution or demands that are not connected to any of the demands Martinsons expressed, like the size of the expansion.

Table 6: The graded specification

Specification	***Rank***	***Definition***
Eliminate wasted time		
Minimise lifting required	3	How many moments must be lifted with the crane
Work environment		
Prevent physical damage to the workers	2	How well are the workers protected from damaging positions, unnecessary waking/lifting, and accidents
Ensure the temperature is in the neutral zone	1	How well the workers are protected from cold draught
Ensure that the psychosocial working environment	1	How mentally demanding is the system
Flow		
Improving the handling of littera and packages	3	How are the routines for handling litteras and packages
Prevent the secondary flows from interrupting the litteras	2	How affects the handling of sawdust and cut-outs of sawdust, and other wastes are handheld
Layout		
Make the recovery of space faster and easier	3	How easy is it to recover space in the system for packaging
Allow flexibility in the packaging	2	Even if the litteras arrives in a no-optimal order, is the packaging not interrupted.
Make the packaging faster	2	Grades the handling and packaging of the walls
Expansion required	1	Smaller expiation is graded higher

8 Ideation

From Martinsons, the workshop, and the private brainstorming several concepts were generated. In this chapter the ideas to solve the problems in the system are presented. The layouts are presented first. After the concepts are described, the details are described.

8.1 Layouts

From the creative phase, six concepts were generated. The concepts were given names based on their layout to differentiate them from each other and make them more accessible to understand. The expansion of the current building for each layout is presented in the corner. The colour coding is the same as earlier but is repeated in the first layout. The flows of packages and litteras are marked in each layout.

8.1.1 Minimal

The basic idea in concept Minimal, Figure 25, is to make the smallest change to the system, yet achieve the goals. The sorting area is expanded to enable sorting of the litteras in the packages when they arrive. In these cases, several litteras can be lifted at the same time, saving time for the crane. Stations for packaging of walls are placed next to the sorting area to lower the distance needed for lifting. The standing stations are explained later. The stations have space to pack two packages at the time, as long as both are not 16 m long. To have better ergonomic while packaging the first level is expanded between the racks, see Figure 26.

The rest of the floor is more or less the same as today, with some added stations for standing packages. By moving more litteras at the same time, the worker can focus more on packing. The EBH is located next to the standing stations.

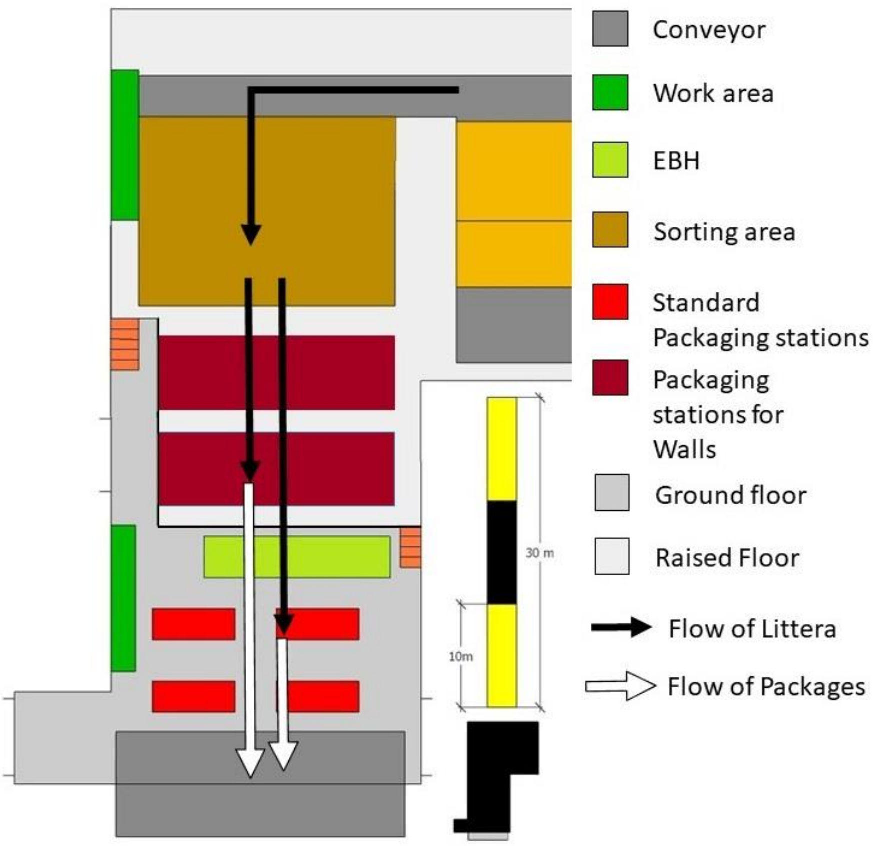

Figure 25: Minimal

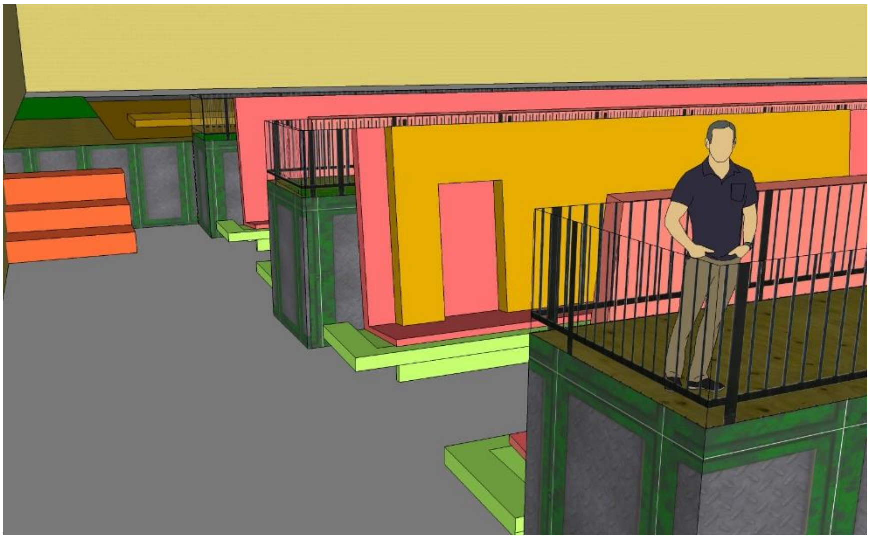

Figure 26: Standing stations in Minimal

When a package is ready, the crane lifts the package to a conveyor that passes through the longer wall. The tractor can either pick up one pack at a time or load it on to a trolley to take several at a time. Minimal could also have a garage/loading area for the trolleys to protect it from snow and rain.

The current system to remove the sawdust is expanded. Two belts are installed on the sides of the CNCs. They transport the sawdust to the end of the CNCs. The side flows are moved to the central belt, which moves all the sawdust and remains under the sorting area to a bin outside the building. The cut-outs either follows the sawdust on a separate conveyor or is transported to the side.

The advantage of this concept is that it is easy to implement this solution. The main drawback is that there is less space on the floor and that the crane is still required for all transportation. The advantage of the waste removal is that it the flow does not turn, ensuring it can remove longer bits, and it can also collect waste from the sorting area. However, when the belt for the sawdust is active, the shipping can become dusty as the sawdust is removed. Lastly, the placement of the EBH has some problems. The crane operator may have problems to see if anyone is standing in the area, causing dangerous situations, and the station requires extra lifting.

8.1.2 Concept L

Concept L, Figure 27, is a variety of Minimal. The difference is that the conveyors move the packages to the side instead of directly outside. This placement gives the tractor an easier time to collect them, as it is on the same side of the building as the storage area. All other aspects of Concept L are the same with Minimal. The advantages of Concept L compared to Minimal are that there is more space for packaging, and the gate outside can be isolated from the rest of the factory, dealing with the temperature. The disadvantage is that there will be a more extensive expansion and a "weird shape" of the building.

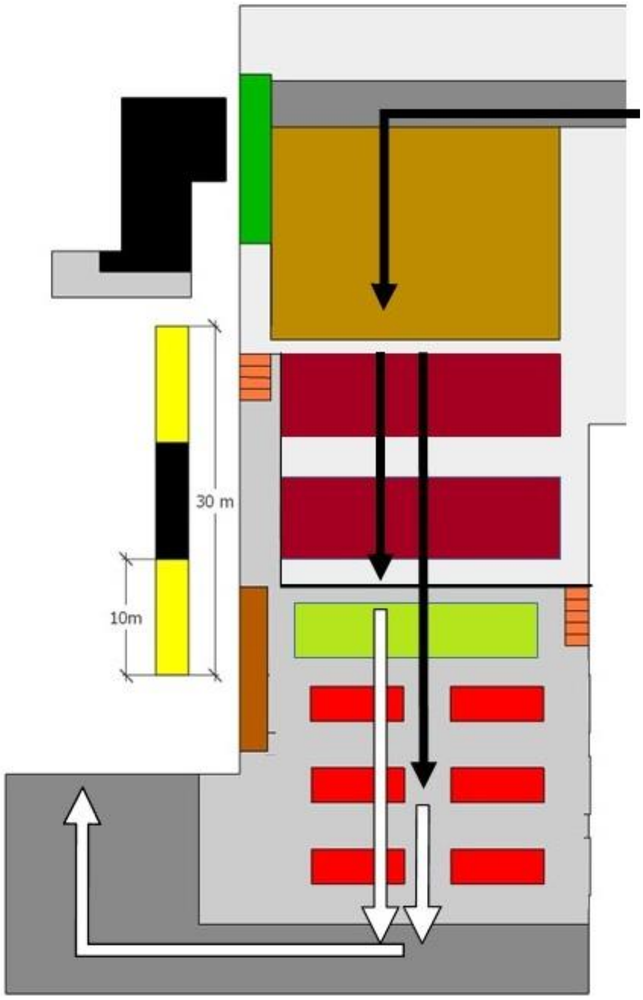

Figure 27: Concept L

8.1.3 Standing Alone

Concept Standing Alone, Figure 28, comes from the position to pack the wall blocks. The standing stations use less space on the floor than packing. On the floor, there are two stations for packages laying down. They are next to the sorting area so the crane operator can have a clear view of them to avoid accidents when placing a littera. The 8 stations for standing packages are placed after the standard stations. It will require lifting to place them on the station, but the packages can be removed with a conveyor. To avoid unnecessary walking in the stairs, the floor level for the sorting is expanded to make a pathway to the stations. It can also be used to store packing materials. When a package is ready, it is moved on a conveyor to a port where a tractor can pick it up.

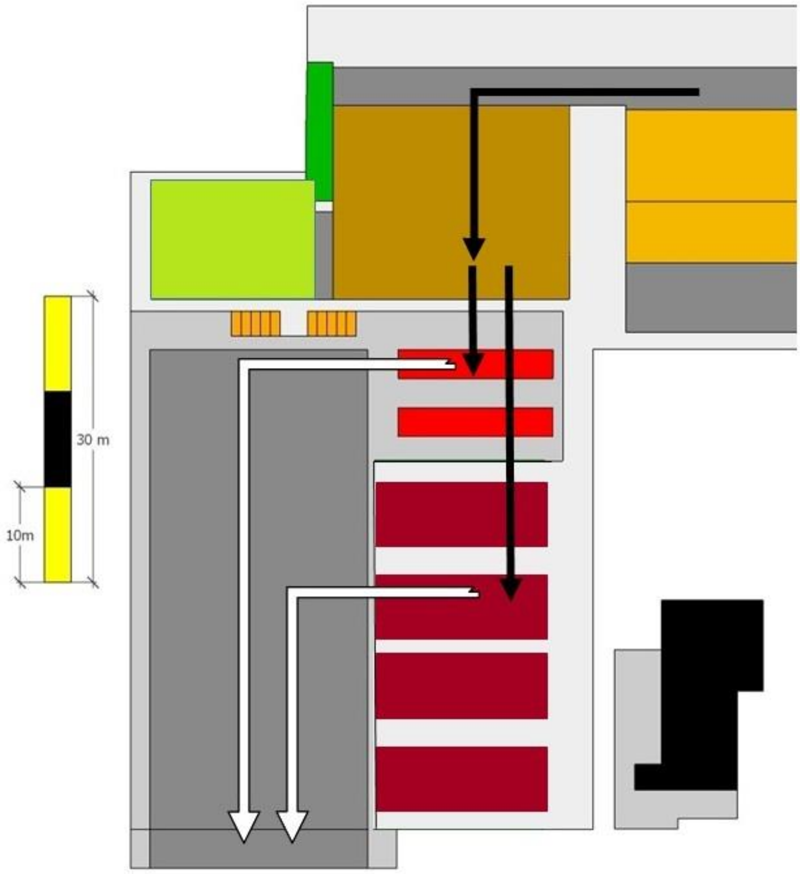

Figure 28: Standing alone

The EBH is placed next to the sorting area, Figure 29. Of all the concepts, Standing Alone has the best place for the EBH as it does not need a crane to transport the litteras to the station and it is close to the packaging, reducing the walking required. The littera that needs repairs is moved away from the sorting area and placed on a lifting station next to the conveyor, to have better posture when working with the repairs. Sawdust is handled the same way as in Minimal. The cut-outs are transported on a conveyor under the sorting area. While the sawdust is on the floor, the cut-outs are only half a meter under the raised floor. They are transported to the EBH, where they are packed, and then moved outside.

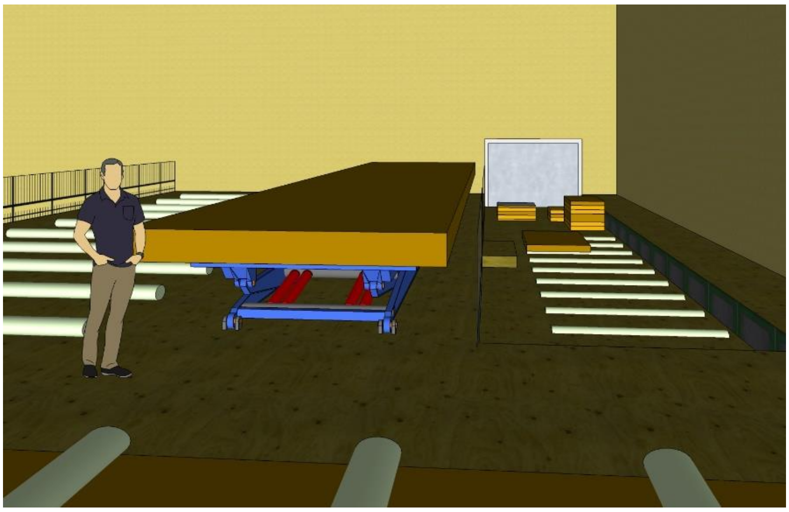

Figure 29: The EBH and cut-out packaging in standing alone

The advantages of Standing Alone are that it is easier to pack the litteras and the placement of the EBH. The drawbacks are that there is still much lifting with the crane. Also, The solution for the cut-outs may cause problems because one worker needs to be in the EBH and pack them, but it does not require the main crane.

8.1.4 Advanced

Compared to the previous concepts, the next concept is more complicated. Therefore, the next concept is named Advanced, see Figure 30, as it takes the first step to more complicated solutions. The "shelf" is expanded, so it covers the entire floor. Workstations and a conveyor are installed on this floor. The conveyors transport the litteras to the station where a smaller crane lifts the litteras to the packing table. The tables can be raised up and down to make the lifting and packaging easier, Figure 31. This solution is inspired by Gestamp Hardtech in Luleå. A box is loaded on the elevator and lifted to the second floor, packed, and lifted down to be shipped to the customer. To prevent falls, there are fences on every edge. The fixed edges would not work at Martinsons, but it is possible to have a counterweight. When the lift goes down the fences are lifted, and vice versa.

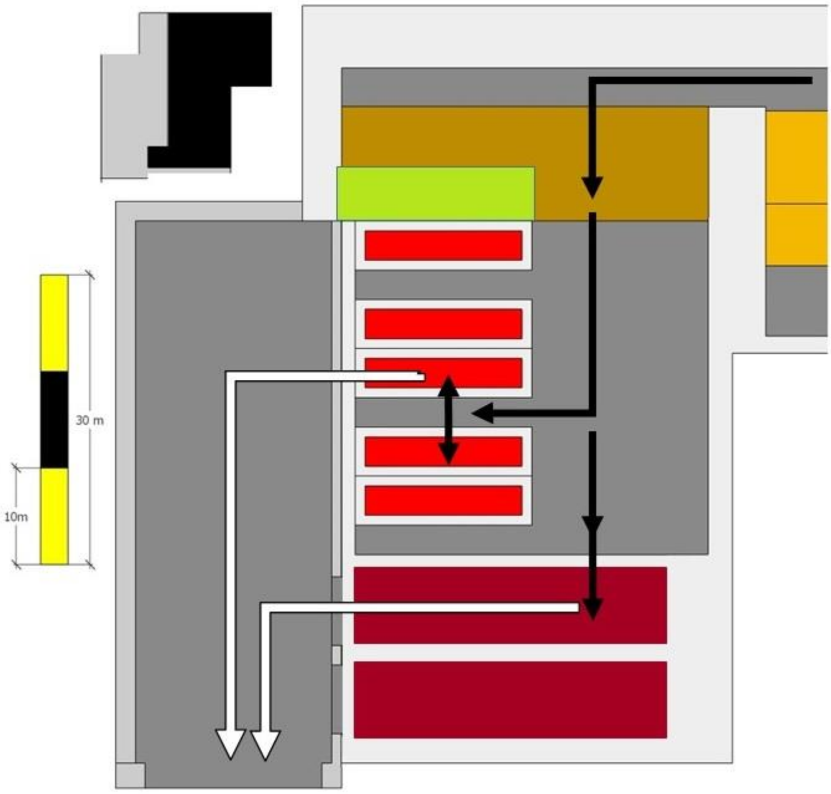

Figure 30: Advance

When a package is ready, the entire station is lowered to the floor with a scissor lift. On the floor is a large conveyor that moves the package to be collected by the tractor. When the package has been moved off the lift, it is raised back to then to be used again. At the end of the room, there are 8 stations for standing packages. Compared to the other concepts, where a rack only has space for one long package or two shorter ones, this version has space for two long packages. The same crane that moves the littera to the station removes the package. A shorter station would have the flexibility the order planning needs. The flow of sawdust is under the sorting area to a bin outside, and the flow of cut-outs can follow it.

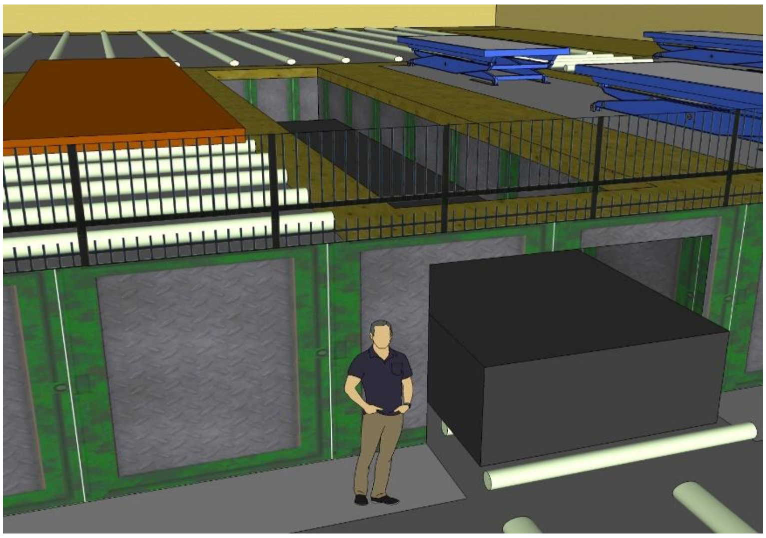
Figure 31: The lifts in Advance

The advantage of this concept is that the need for the crane becomes a fraction of today's needs, it is only used for the standing packages and short lifts at the standard stations. The recovery of space becomes quicker as the workers only need to press a button. The disadvantage is that the investment will be substantial and there are many moving parts. Lastly, the EBH has a weird placement, compared to other concepts.

8.1.5 TDR

Total re-design or TDR, Figure 32, is similar to Advanced. The difference is that TDR requires a smaller expansion compared to Advanced. A central conveyor moves the litteras that need to be packed, laying down, to the stations. There, the litteras are lifted with a small crane to the table, on which the sheet is placed before. Once all the litteras are placed and packed, the package is lowered to the floor and placed on a conveyor. The conveyor moves the package to the side to a gate from where it is collected.

The wall litteras are lifted from the conveyor directly to the racks and packed. The standing packages are lifted with the crane to a separate gate, see Figure 33, to be moved outside. The result is that the standing packages are collected on another side of the building than the standard packages.

Because of the conveyor under the floor, the sawdust cannot be moved under the floor as in earlier concepts, meaning that it must be moved to the side or be removed by ventilation. For both alternatives, the remains are a problem. The longer bits cannot make a 90° turn or be moved with a fan. They can be moved to the side and collected later instead. The cut-outs are laid on a conveyor and moved to the inner wall.

TDR has the advantages that the sorting area is larger than other concepts, has better placement of the EBH and requires less expansion compared to other concepts. The disadvantages are that it can be hard to have a stable platform if the packages are moved under it and that lifting is still required.

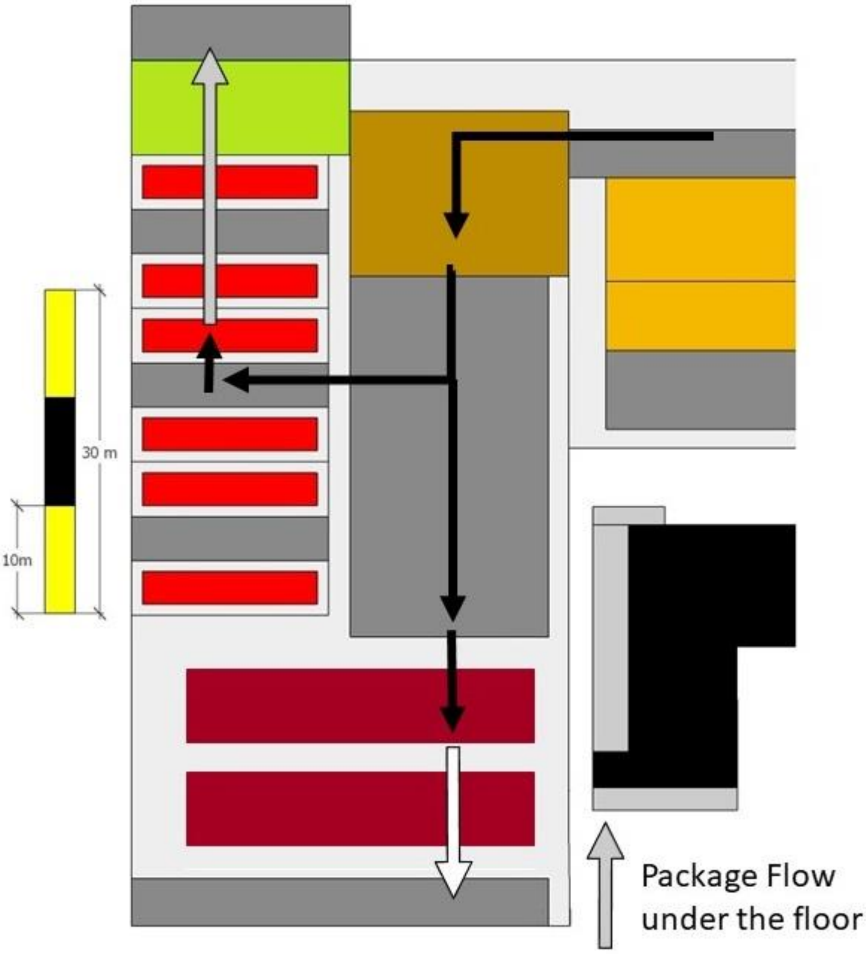

Figure 32: TDR

Figure 33: Out-loading of standing packages in TDR

8.1.6 Split

Split, Figure 34, divides the flows of walls and other litteras. All litteras arrive at the sorting area and are then placed on a central conveyor. It moves the litteras either to the right, to be packed as usual, or to the left to be packed standing. When a standing package is ready, it is moved to the side of the conveyor and transported outside. The standard packages are moved to the other side instead. Here, several stations are similar to the ones in Advance. Each pair of stations has a crane that can lift one littera. The cranes are only used to lift the littera to the stations, which takes less time compared to today. Once the packages are ready, they are lifted to the floor to a conveyor. The packages are moved to the other station, see Figure 35, to finally join the standing packages at the gate. The EBH is similar to standing, as it separates the flow of littera and waste.

The handling of litteras and packages are improved by splitting the flows. Split has the best material handling of all the concepts. Split also has the highest flexibility and capacity ensuring a higher flow efficiency. The crane would only be used for small lifts from the conveyors to the stations.

The major problem with Split is that it has the largest expansion of all the concepts. Split also have some problems with the handling of the standard packages. The handling has some uncertainty regarding the transporting of the standard packages below the other stations, that needs to be examined more. If the problem with moving the packages under the station cannot be solved; the packages must be removed the same way as in Advance. It would be more practical to have a separate gate for the standard packages in this case. The expansion would result in an even more significant expansion to the courtyard. One advantage would be that the flows would be entirely separate and that a trolley could be placed between the gates so the tractor could move several packages to storage at the same time.

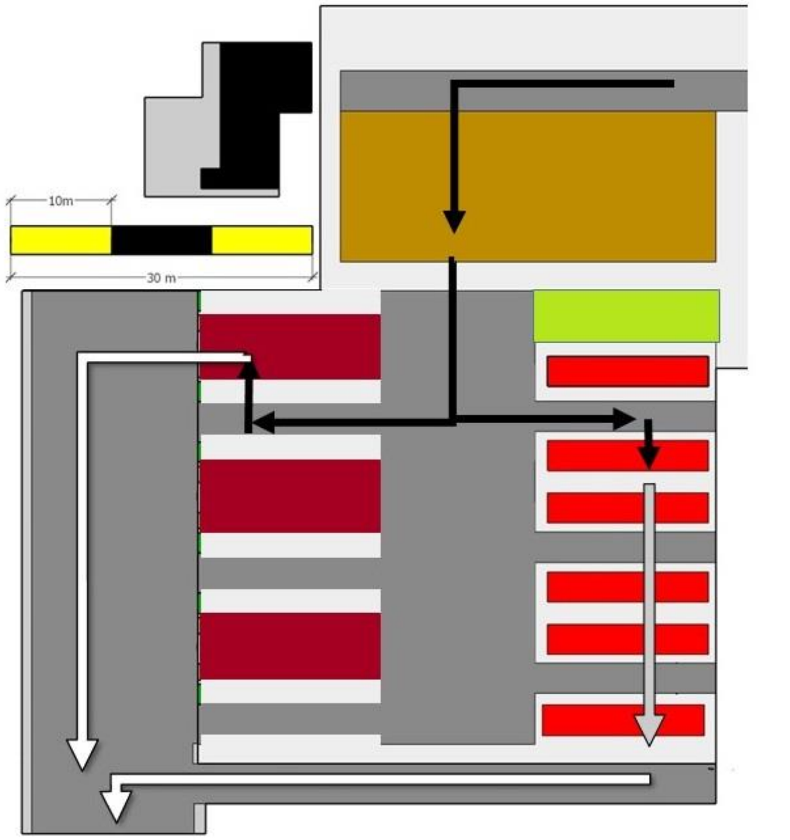

Figure 34:Split


Figure 35: The exit for the conveyors under the floor

8.2 DETAILS IN THE CONCEPTS

This section describes the details present in several of the concepts.

8.2.1 Standing packaging station

As stated earlier, it is not optimal to pack the wall litteras laying down, both for ergonomic and logistic reasons. Martinsons has an idea on how to pack them in a standing racket. It consists of three parts, the foundation that may have a conveyor, an L-shaped rack and the work area, see Figure 36. The rack is tilted, so the litteras are stable.

Before placing the first littera, the sheet is placed on the rack, to make the packaging easier. The littera is lifted vertically, instead of lying down and placed on the racket. Each new littera is screwed to the other littera. Once all the littera are all placed, the sheet is pulled over and attached. The worker goes down to the floor to fasten it. While the worker is on the floor, supports are added to the sides for extra stability while moving the packages.

Once packed, the racket can either be turned so that the packages can be placed on a conveyor or lifted away. The idea is primarily for walls, but all packages can use it. This solution would use less space on the floor and prevent a dangerous position while packaging, but there could be problems with marking weaknesses and much walking in stairs.

The design Martinsons created is an independent model that can stand anywhere on the floor. This alternative can cause ergonomic problems. The workers have to go up and down many times during the day, putting pressure on the knees. To lessen these risks, a new design has been created. It consists of two stations facing each other with a raised work area behind each station, see Figure 37. These areas are connected to the raised floor level, thus reducing the walking in stairs. In one of the shorter ends, a stair that the worker can use to get to the space between the stations is located, to attach the supports on the packages. The other end is open and is used to move the packages to the conveyors. To prevent accidents, the work area has a 1m high fence, and the area between the stations is visible from all areas of the station.

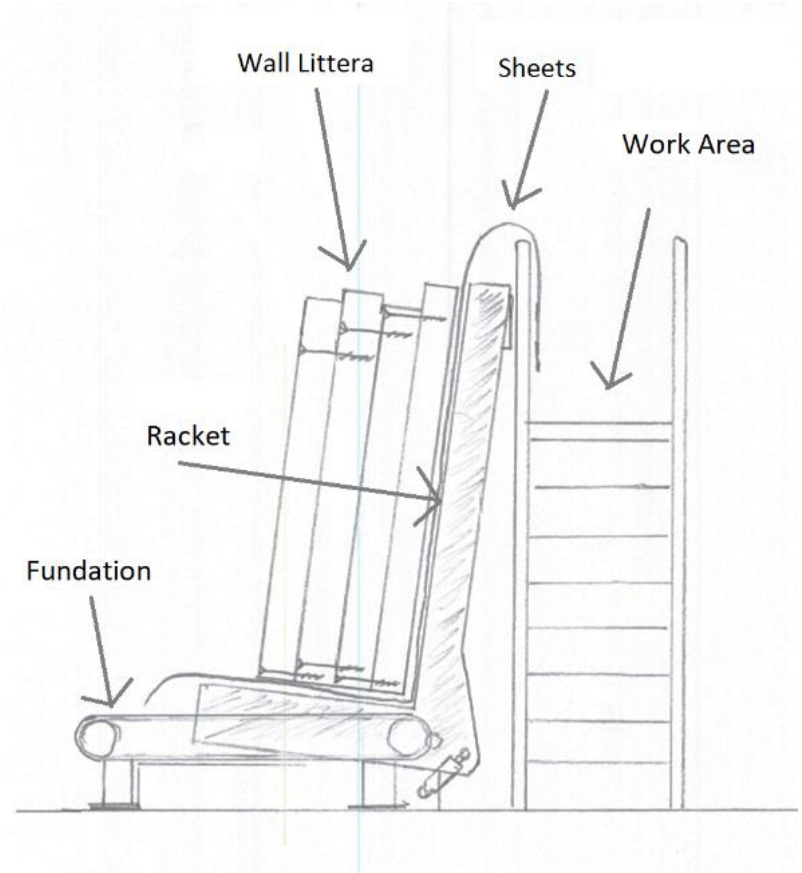

Figure 36: Sketch of the rack for wall littera (Martinsons n.d)

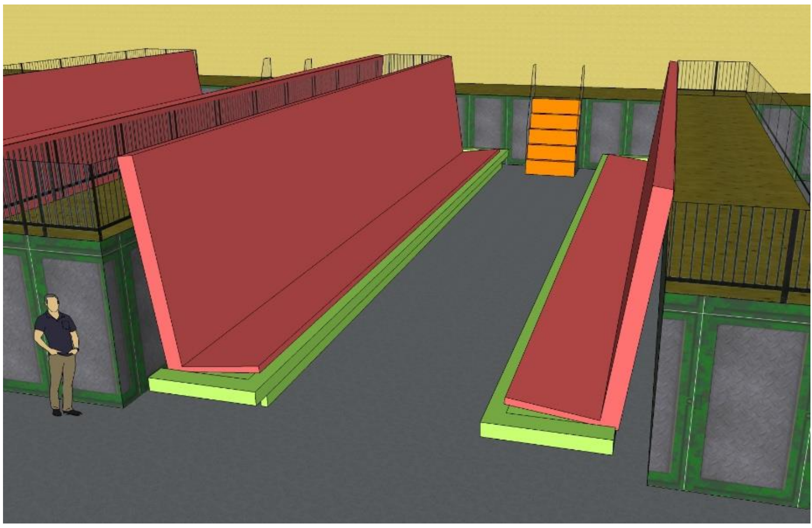
Figure 37: The packaging stations combined with the raised floor

The stands can be improved by installing hydraulic cylinders to raise the rack to a horizontal position level with the raised floor, see Figure 38. This alternative has several advantages to the stationary version. All littera would be lifted the same way to the stations and the workers would not need to go up and down stairs to attach the supports. This solution would cost more and be more complicated, and the cylinders may not be enough to lift the heaviest packages. This solution is inspired by two edmolift products: tilts and arm lifts.

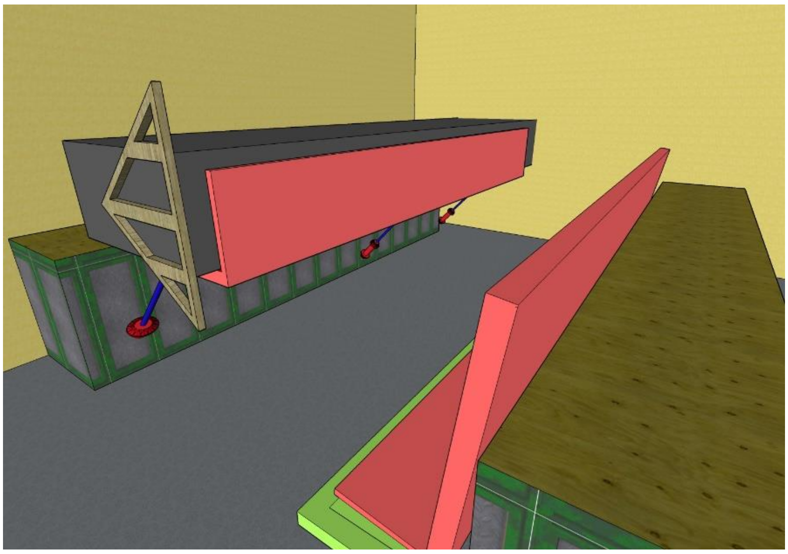

Figure 38: Standing packaging stations with lifts

8.2.2 The sheet holding and pulling

An unnecessary amount of time is spent on positioning the first littera during the packaging. The primary problem is the swinging of the litteras and the need to adjust the sheet that also takes time. During the workshop, an alternative to the wagon was proposed. In the new system, every station has its own fixed rack with the sheets ready to use. To save time when placing the first littera, each station also has a holding arm that can stretch the littera. This would reduce wasted time in the shipping, especially if the pulling could be automated. It would need to be adjusted to several lengths, and it locks the positions. This idea is used in all the concepts.

Martinsons has expressed a desire to have lifts on all the stations, partly to allow for adjustable height. The tables would remove the need for holding the sheets, as the sheets are placed on the tables. The presented idea is still useful as it avoids the need to bend down and pick up the sheet when packaging.

Other companies like Snidex, Burträsk, and Nordic light, Skellefteå, have machines to pack EU-pallets. In these machines, a plastic sheet is placed on the pallet to cover the top. Another machine then rotates the pallet and wraps the pallet in plastic. Snidex has a similar solution for when the package is extra-large, more than a standard EU-pallet. The pallet remains stationary while the machine goes around the package and wraps it in plastic.

8.2.3 Packages removal

One of the ideas from Martinsons and the workshop was to move the packages with a conveyor instead of the trolley. There are two alternatives: through a gate in the short wall of the shipping, alternative A in Figure 39, or by a smaller gate to the side, alternative B. Alternative A requires a longer gate but would not change the shape of the building. Alternative B needs a smaller gate than B, but a longer expansion of the building that will affect flows outside the factory. Both solutions need a garage to protect the conveyor from being covered in snow during winter, but this could help solve the problems with the draught by having an air gate.

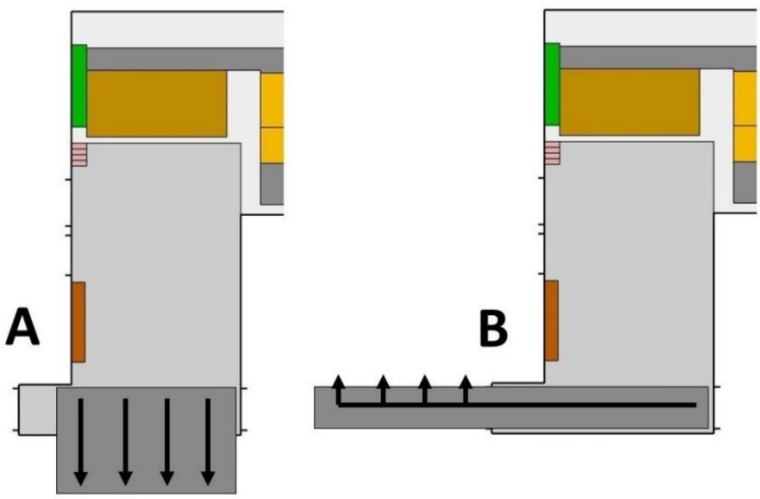

Figure 39: Example of how the conveyor for the packages can be placed

8.2.4 Internal handling

One other idea was to have a central conveyor that feeds the littera to one of the several workstations. These stations would have an automated packaging and be able to move them outside. The conveyor would use much space and require an investment, but the need for the crane would decrease drastically. It would still be used sometimes for longer littera and to speed up the sorting. Smaller cranes or turntables are used to lift the litteras from the conveyor. Both solutions have problems, as the cranes take time and the turntables have difficulties to provide space between the litteras.

The gates are a problem as they allow cold air to blow through the factory. Cold draught is a problem for many industries. It can be solved in two ways. The first is to lower the airflow. It can be achieved by either having smaller gates or by hanging of airlock. There should always be at least one gate between the outside and the workers. Lastly, an air curtain that blows hot air when the gate is opened makes the situation even safer.

8.2.5 Sawdust

In the workshop, it was unanimous that the sawdust should not enter the shipping area. The question is rather what way it should be removed. Martinsons presented an idea to move it to the side of the factory behind the expanded section, placement A1 in Figure 40, or the other side, A2. The belt inside the machine is expanded to the sides and transports the sawdust to a new belt that removes it to the side to a bin outside, like the current system. The same system can also deal with the cut-outs. However, the longer bits cannot make a 90°turn easily and would still need to be handheld manually. Martinsons has no solution to it. An alternative is to instal a filter below the CNC that separates the sawdust from the bits. Sawdust and smaller bits pass the filter and is removed by the conveyor, while the larger bits are collected manually from the sides.

An alternative is to move it under the sorting area to a bin next to the gates, placement B. This system can handle long bits and can collect the dust from under the sorting area. However, there is a risk that the shipping will become dusty when the belt is on.

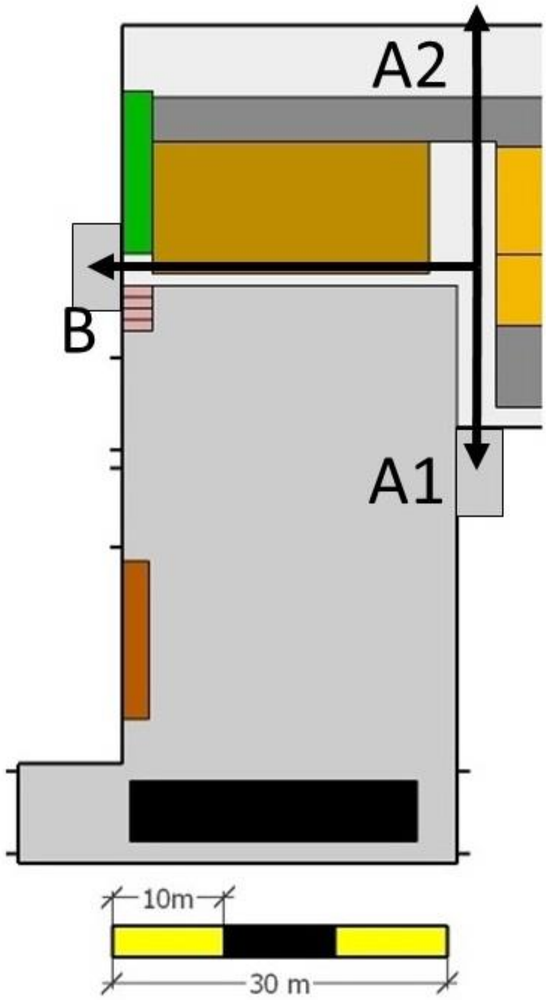

Figure 40: Alternatives for the flow of Sawdust and Cut-outs

Both Snidex and other parts of Martinsons are using fans to remove sawdust. In its most basic form, it is a giant vacuum cleaner that collects the dust and transports it either to a furnace or to storing elsewhere. This system can work in the first CNC and sander. The second CNC has bits in the sawdust that the fan cannot handle. A filter could be used to separate the sawdust from the bits. The bits could be collected later by hand or with a conveyor.

Lastly, to entirely avoid the sawdust in the sorting area a "vacuum gate", see Figure 41, could be installed between the plunder station and the sorting area. The gate has a blow or suction system to remove the sawdust. The system activates when the littera passes through the gate. It could also have some knives or other tools, possibly with a CNC controller, to remove the remains. This system would result in no sawdust in the sorting area, improving the environment and saving time. It could also be designed to remove some of the remains. However, there is a risk of damage to the littera, especially on the sanded littera.

8.2.6 Cut-outs

Compared to the packages of litteras, the packages of cut-outs are more uniform with fewer variations. With this in mind, they can easily be packed by a machine, as there are no variations to them. During the workshop, several participants believed that it could be automated. The conveyor sorts the litteras with "holes", with several regular dimensions. The cut-outs of larger sizes pass the hole, but the ones of the right size fall to a pallet. The larger pieces would pass the hole to the next hole. The pallet is removed and changed to a new one when the last one is full. Another possibility would be to move the litteras with a crane or a robot to achieve a similar effect. This flow could follow the one for the sawdust, as both should not interfere with the packaging of litteras.

Another solution that is used in Standing Alone is to have a secondary conveyor under the sorting area. It leads to the EBH where a new crane lifts it to a pallet. It would separate the cut-outs from the main flow.

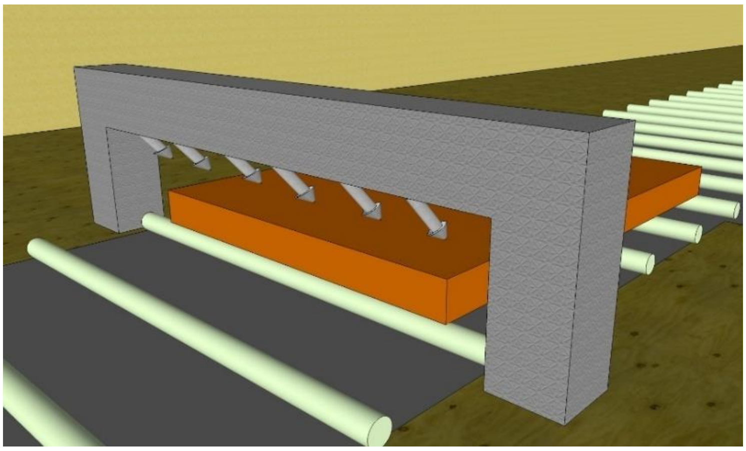

Figure 41: Vacuum gate

9 Final evaluation of solutions

This chapter describes the valuation of the concepts and how the final solution was chosen. The chapter starts with the value matrix and how the concepts were graded. The results are then summarised, and a final solution is chosen.

9.1 Valuation

A value matrix was used to evaluate how the concepts fulfilled the specification. The specifications used are presented in Chapter 7.2. The result from the value matrix is presented in Table 7. The definition of the ranking of the different aspects is presented in Appendix 6.

9.2 The motivation of the evaluation

This section evaluates the grading for the specification. The aspects are evaluated one at a time, except the current and perfect stage.

9.2.1 Minimise lifting required

Advance, TDR and Split only requires the crane for short lifts to the stations and the standing stations. This situation represents 5 on the scale. Minimal and Concept L requires long lifts for both litteras and packages, making them no different than today, giving them 3. Standing Alone requires only lifting to the stations, placing it between the former at 4.

Table 7: Value Matrix

Specification of the solution	Rank	Current stage	Perfect stage	Minimal	L	Standing Alone	Advance	TDR	Split
Minimise lifting required	3	3	6	3	3	4	5	5	5
Prevent physical damage to the workers	2	4	6	4	4	5	5	5	5
Ensure the temperature is in the neutral zone	1	3	6	5	6	5	5	3	5
Ensure that the psychosocial working environment	1	5	6	4	4	5	5	5	5
Improving the handling of littera and packages	3	4	6	4	5	5	5	4	4
Prevent the secondary flows from interrupting the litteras	2	3	6	4	4	6	5	4	5
Make the recovery and use of space faster and easier	3	3	6	3	3	5	5	4	4
Allow flexibility in the packaging	2	3	6	4	4	4	5	4	6
Make the packaging faster	2	3	6	4	4	4	4	4	4
Expansion required	1	6	6	5	4	4	4	3	3
Total score		70	120	76	79	94	97	84	92

Score	3	4	5	6
Percent fulfilment	0-30%	30-60%	60-95%	95-100%

9.2.2 Prevent physical damage to the workers

Standing Alone, Advance, TDR and Split all need less walking in stairs compared to Minimal and Concept L. However, the former uses more conveyors that can cause accidents if the workers are not careful.

9.2.3 Keep comfortable temperature

Minimal, Standing Alone, Advance and Split have an airlock that helps with reducing the effect of the temperature. It improves the situation compared to today. TDR has two gates that risk allowing air in. Concept L is the best solution in regards to the temperature. Its long packages conveyor allows for several doors. Concept L receives 6.

9.2.4 Ensure that the psychosocial working environment

In the current system, the communication between the workers in the sorting area and those on the floor is easy as they can have eye to eye contact. In Minimal and Concept L the worker in the sorting cannot have direct contact with those working with the standard packages. These problems do not exist in the rest, as the packaging is on the same level as the sorting.

9.2.5 Improving flows of littera and packages

The expanded sorting area of Minimal improves the handling of the litteras compared to the current stage. Therefore, Minimal receive 4 in the ranking. TDR and Split have some uncertainties regarding the flows resulting in that they also receive 4. L, Standing Alone and Advance are all improved with few uncertainties. They receive 5.

9.2.6 Prevent the secondary flows from interrupting the litteras

Minimal and Concept L use the solution Martinsons have proposed. It will improve the situation today, but there is a problem with longer bits. Minimal and Concept L receive 4 for improving the situation but have some problems. TDR has similar problems and receives 4 as well. Advance and Split solve the problems better than Minimal and L, resulting in a better score. Standing Alone has the best handling of the sides flows with the EBH section. It separates the side flows completely from the main flow. This situation is clearly 6.

9.2.7 Make the recovery and use of space faster and easier

In both Minimal and Concept L, the recovery and use of space are identical to the current stage. However, in Advance and Standing Alone, the situation is greatly improved with the automatic removal. Split and TDR are 4 because of the organisation around the package removal under the floor.

9.2.8 Allow flexibility in the packaging

Split has most stations and the largest sorting area, resulting in perfect flexibility. Advance has a similar level, but not as many stations resulting in 5 instead of 6. Minimal, Concept L and Standing Alone all have problems with the size of the sorting area and the number of stations.

9.2.9 Make the packaging faster

All the concepts have improvement to the current stage with the lifts. Still, the packaging is manual in all concepts.

9.2.10 Expansion required

Minimal will not need any larger changes in the building. It only needs a gate and an airlock. It gives Minimal 5, as it still needs some changes. Concept L is similar to Minimal but requires a larger expansion, lowering its score to 4. Standing Alone and Advance both requires a larger expansion, but not as complicated as TDR and Split. Therefore, 4 is given to Standing Alone and Advance, and 3 to TDR and Split.

9.2.11 Current stage and perfect

The current stage has many problems, resulting in most of the aspects having lower scores. All handling requires the crane giving it 3. Regarding the ergonomic, the psychosocial environment is excellent but some problems with the machines and the fact that a worker is sometimes alone in the workplace results in only 5. The current stage has some risks for MSD, but there are tools to avoid it, and the gate is opened a lot that affects the temperature a lot, resulting in 4 for ergonomics and 3 for the temperature. All flows can be improved, especially the side flows. They are all using the crane, but the flow of littera is better than the side flows. The flow of littera receives 4 while the side flow receives 3. The flexibility, packaging and space optimisation and recovery all need much improving, giving them all a 3. The current stage will not need any change, so expansion required is a 6. In the perfect stage, all aspects are fully fulfilled.

9.3 Summarised

The highest score was achieved by the Concept Advance with 97, followed by Standing Alone with 94. Split was the third best with 92. TDR placed 4; with a score of 84. Concept L became second to last with 79. Minimal received the lowest score, 76.

The low score for Minimal and Concept L was expected. They are limited to the current building. Minimal had the most restriction and has the lowest score, with Concept L being a little better than Minimal. The deciding factors are that Concept L dealt with the temperature and bottleneck better than Minimal. It was expected that Standing Alone would be closer to the lower half. Standing Alone is on a shared third place with TDR.

Advance and TDR were expected to have similar scores as they have much in common. The main difference is how the packages are removed. Advance handled the removal and used the crane less than TDR. However, TDR required a smaller expansion, had better placement of the EBH and handled the cut-outs better

Split received the third highest score. Split is the most complex concept and required the most extensive expansion. Much space used to transport littera, except if the packages cannot be removed from the other stations. Split had the least use of crane of all the concepts. It would save much time.

So, which one is the best? In discussion with the supervisor at LTU, it was revealed that the concepts are not on the same level. They have vastly different complexity. Minimal, Concept L and Standing Alone are all tied to the current building and can be achieved with a small investment, in time and money, while Advance, TDR and Split are visions that may take several years to implement.

Split and TDR are both complicated and hard to implement. The advantages they have are used in other concepts, so there are removed from further detailing. Minimal and Concept L do not solve the problem entirely but can be implemented quickly and Standing Alone and Advance both require a medium investment and solve the problem.

With this information, an implementation plan with several steps is recommended. The first expansion should start as soon as possible and use concept Minimal as a stepping-stone to concept Standing Alone. The production may continue while the building is expanded for Standing Alone. When Standing Alone is fully implemented, Martinsons must decide if Standing Alone is enough or continue to implement Advance, depending on the costs and current demand.

10 Detailed solutions

This chapter presents the detailed solutions. Compared to the version in the value matrix, the final versions are modified to fit in the proposed expansion plan. Lastly, the needed machines and expansions for each step are calculated to make an economic analysis.

10.1 Improvements to existing concepts

All concepts received some improvement compared to the original version. For example were some aspects from other concepts were combined and new solutions were determined. The flow in all the improved concepts is the same as in the original. Appendix 7 has more detailed figures of the concepts.

At the same time, the machines and the expansions required for the concepts were determined. It was used to both better understand the concepts and to make an economic calculation.

10.1.1 Improving Minimal

Minimal is not supposed to be used by itself. Instead, it should be used as a stepping stone to Standing Alone. It has been changed to be easier to implement in the current building. Firstly, the expansion of the sorting area and two standing stations are removed from the original idea, Figure 42. One more standard station is installed that doubles as a packing station and the EBH. A lift is instaled next to the EBH, see Figure 43, To handle the flow of cut-outs. When a pallet with cut-outs is full, it is moved to the edge and placed on a lift. The cut-outs are then packed and removed through the conveyors that collect the packages or by one of the other gates. The later would affect the temperature more.

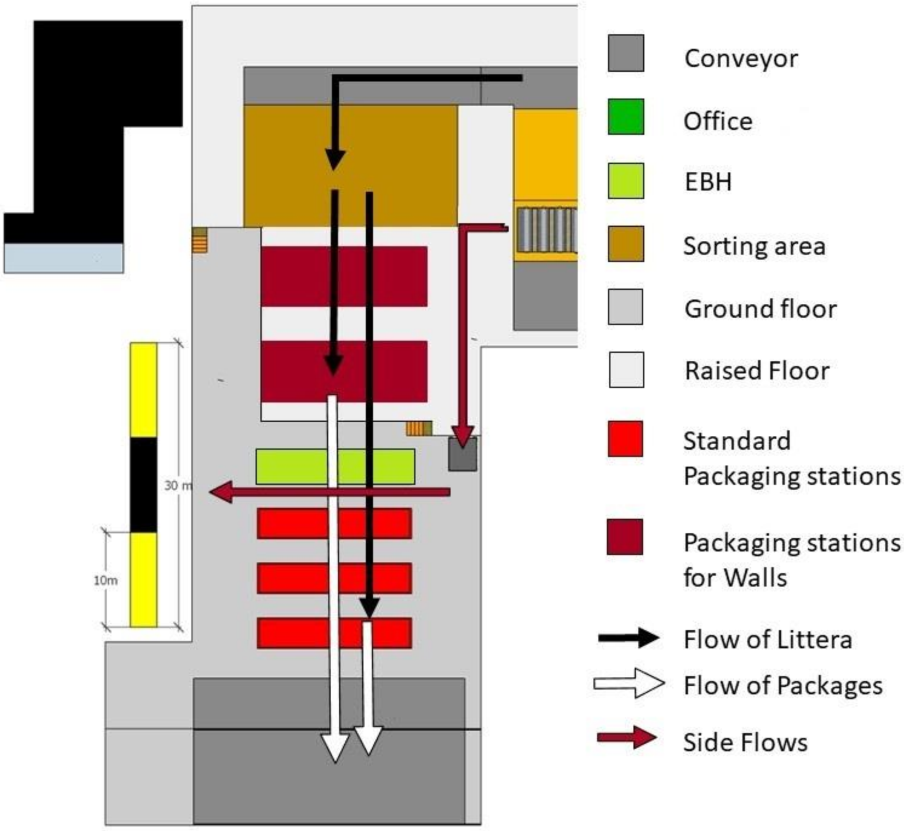

Figure 42:Improved Minimal

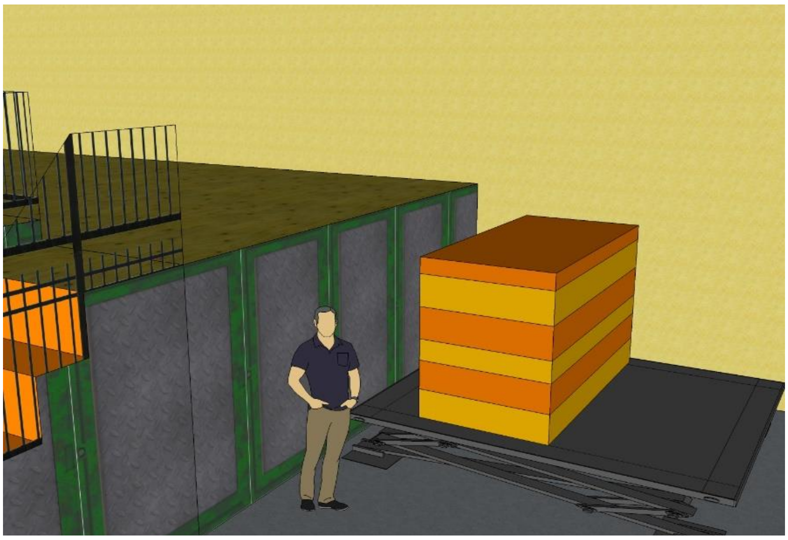

Figure 43: Cut-outs handling in Minimal

10.1.2 Improving Standing Alone

Concept Standing Alone received some changes from the original idea, see Figure 44. First, the number of standing stations was reduced to six. The extra space was used to have a more standard station, maintaining flexibility in the packaging. The placement of the standard and standing stations was changed, so the standing stations were closer to the sorting area. The main reason is to get an easier expansion and to lower the distance that the wall litteras need to be lifted. The floor litteras are sorted in the expanded sorting area and lifted to the floor several at a time.

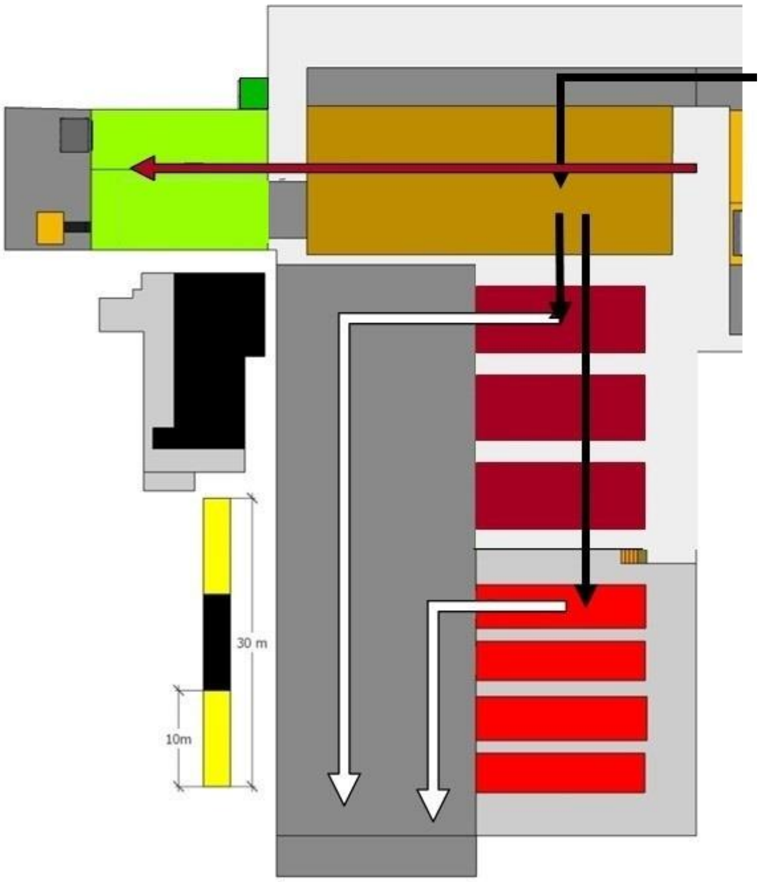

Figure 44: Final layout of Standing alone

The EBH receives two smaller changes. First, a small building is added to its side, called side exit. The side exit is used as a storage for the packed cut-outs and the bin for the sawdust. This area has two openings connected to the EBH. The first one is a gate used to move the packed cut-outs outside and deliveries of material for repairs, it is usually closed. The second one is for the belt for the sawdust. It has an own gate to prevent any draught. The last change on the EBH is that the conveyor that moves the damage littera also have a lift. Next to the EBH and sorting area, a small office is added, where the workers can use the computer without the risk of dust. The final EBH is presented in Figure 45.

The sorting area has been increased to the same sizes as in Advanced. The main reason was to make the expansion to Advance easier, and the EBH does not need to be moved with this placement. The expansion results in either a weird shape on the building, if the extra space is ignored, or with a large area with no planned purpose. If this area is built at the same time as standing, it can be used as storage for tractors and other larger machines. In the sorting area and EBH, a well connects to the belt for the sawdust, see Figure 46. The well is used to remove any sawdust and remains from the sorting area.

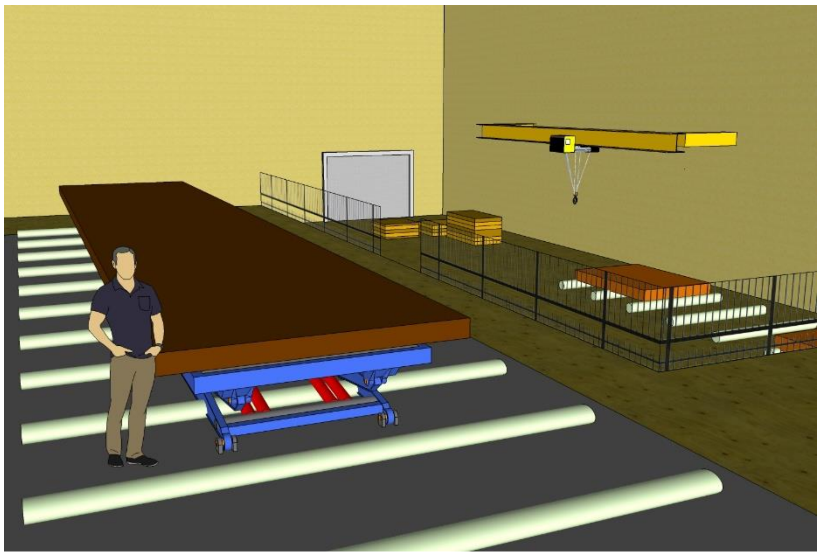

Figure 45: The new EBH

The remains and adjustments should be dealt with in the CNC; anything else is unacceptable. If the CNC cannot be improved to remove the remains, the vacuum gate with the blades should be installed between the plunder station and the sorting area to save time in the sorting area. An alternative is to wait to remove them until the litteras are on the packing table. There, the worker can adjust the height to have a better working position. Bottlenecks can also be avoided as the litteras are not on the conveyor longer than necessary, making space for new ones. The remains that are removed are collected and transported to the belt for the waste from the CNC-machines.

The investment needed for Standing Alone is presented in Table 8.

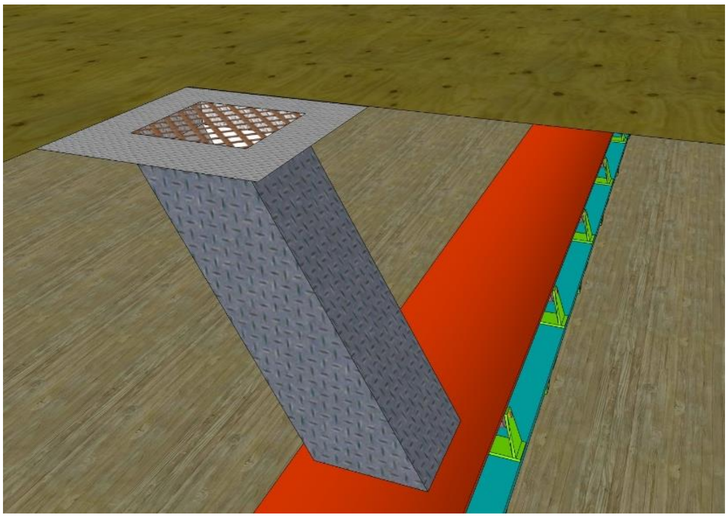

Figure 46: The remains wells in the sorting area

Table 8: Parts needed for Standing Alone

Building	1600 m2 (excluding part of Advance)
Scissor lifts	8 for the packaging + 2 for the EBH
Expanding the crane	Length: 10 m
New crane	1 for the cut-outs
Wall packaging stations	6 stations
Raised floor	978 m2
Conveyors for packages	23*60m
Conveyors for litteras	37*10m
Conveyors for the EBH	20 m
Conveyors for cut-outs	42*2m
Transporting belt for sawdust	178 m
Turntable for the littera	1-2

10.1.3 Improving Advance

From the original version of Advance, the EBH is moved to a position identical to in Standing Alone, including the handling of cut-outs and sawdust. The final version is presented in Figure 47.

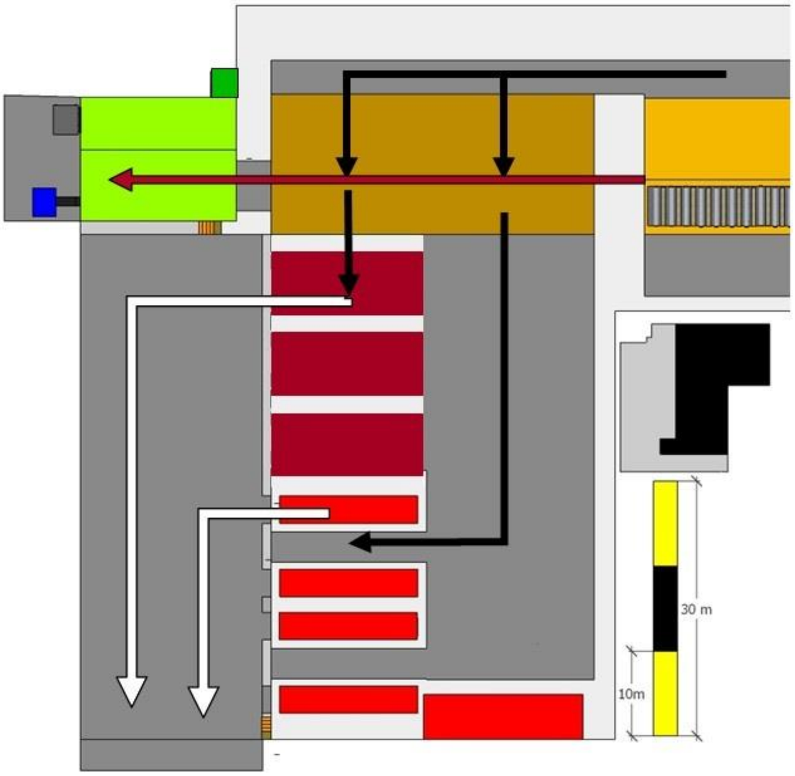

Figure 47: Advance

The positions for the standard and wall packages are changed, placing the standing stations closer to the sorting area, to make the handling of the wall littera easier. The sorting area can be roughly divided into two parts, the normal and the wall part. The standard part is similar to the sorting area today. The other area, the standing section, is closer to the EBH and the standing station has a table to raise the littera before lifting them to standing positions. Lastly, cranes are installed next to the standard stations to lift the littera to the tables from the conveyor, See Figure 48.

As Standing Alone needs a more extended building to maintain the capacity, two more stations for standing litteras are installed in Advanced, at the expense of one station for standard packages.

Lastly, at the end of the primary conveyor is an area for storage of the plastic sheets and other materials added. In Table 9, the investments needed to change Standing Alone to Advanced are shown.

Table 9: Parts needed for Advance

Building	1150 m^2
Lifts for the standard stations	4
New crane	2 for the standard stations,
Raised floor	2173 m^2
Conveyors for litteras	52*20 m

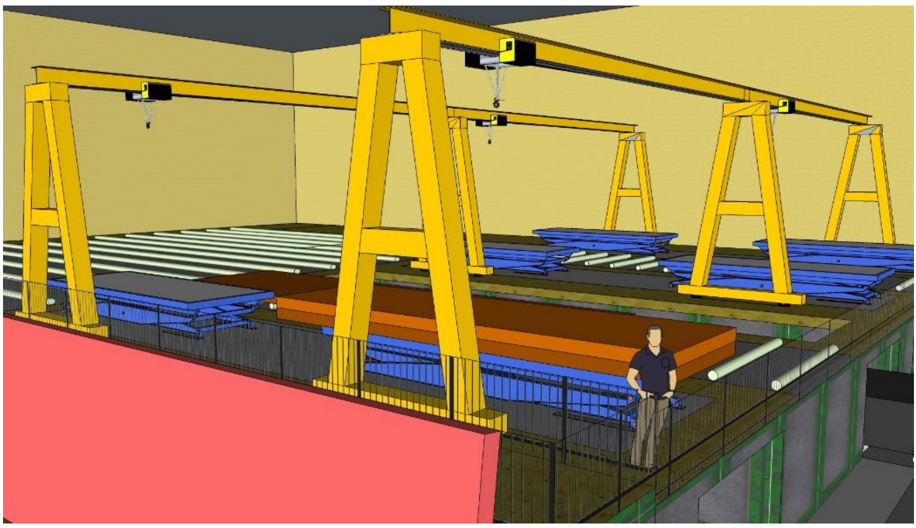

Figure 48:Cranes in Advance

10.2 Economic analysis

The costs for expanding the factory are calculated based on one of Martinsons' products, the industrial hotel. It consists of large compartments that can be combined to achieve different results. For the first expansion, to Standing Alone, 11 compartments would be needed. The approximate cost, including installation, is 6,300kr/m^2, the calculation is explained in Table A in Appendix 8.

Martinsons has received an offer from Admolift AB for lifts to the packaging station. Each of them costs 110,000kr each, and each station needs two lifts to be able to lift the longest littera. The same lifts are used in Advance to lower the packages.

The costs for the cranes are calculated with the help of lihå Produkter AB. After a discussion regarding the solution, an approximate cost was given, summarised in Table B in Appendix 8. The standing stations are assumed to cost 50,000 SEK each. Any other costs for the expansion are, compared to the crane, lifts and expansion, considered irrelevant. The investment costs for both concepts are presented in Table 10.

Table 10: Investment cost calculation

Standing	Cost (SEK)	Advance	Cost (SEK)
Expansion	10,690,000	*Expansion*	7,257,000
Standard working stations	1,100,000	Lifts for packages	880,000
Standing stations	300,000	Cranes at stations	1,000,000
Crane in the EBH	25,000		
Expanded crane	30,000		
Total cost	**12,145,000**		**9,137,000**

The payoff calculation assumes that Martinsons invests in two steps, with the second investment two years after the first. The first investment is Standing Alone and the second is Advanced. The payoff time is calculated from after the second investment.

Table 11 presents the profit required for each month a payoff time of 4,6,7 and 10 years. The calculations are presented in Appendix 8.

Table 11: Payoff time calculation

Payoff time	Required profit each month
4	254,000 SEK
6	198,000 SEK
7	178,000 SEK
10	137,000 SEK

10.3 The strategy of the expansion

Martinsons should expand the shipping in three steps to solve the problems, see Figure 49. However, at the same time as the first step, the CNC and production order should be improved to avoid the unnecessary work, and achieve a more even workload and remove variations. Both of these changes will improve the flows and throughput (Liker, 2013; Modig & Åhlström, 2015).

Step 1 should start early 2018. It should consist of a renovation of the inside of the current factory to Minimal. It will help the current system by making the lifts to the stations faster compared to today. However, this will not solve the problems but can be used as a stepping stone for the second expansion, Standing Alone. It should focus on first expanding the building while maintaining regular production. The extra expansion for Advanced could be made at the same time to save time and money. After the building has been expanded, the focus should be on the EBH. It will save time by separating the waste flow from the littera and crane. Lastly, the internal design should be changed. The packaging stations should be built before the conveyor.

If the new system solves the problems and Martinsons can increase their production to be in level with the rest of the factory, Advanced is not needed. However, if more needs to be done, Martinsons should implement Advance. The expansion should start with expanding the building, if this was not done earlier. Martinsons should then install the raised internal floor and the stations with lifts and conveyors should be installed. Lastly, the cranes for the normal packages should be installed.

In addition to the expansion, the workers should be able to solve more of their problem by themselves. The first step for this should be to standardise the work in the shipping, followed by implementing 5S in the factory. The ending should be to have continuous improvements in the shipping that solve problems directly (Liker, 2013).

Martinsons should oversee the routines with improvements in the shipping. The time from when an idea or complaint is reported to the first steps for action must be lowered to reduce the effects of the problems and to show the workers that they are important and that their opinion matter. The current system, where changes are slow, risks making the workers doubtful of future changes, as the workers become resilient to new changes (Røvik, 2008).

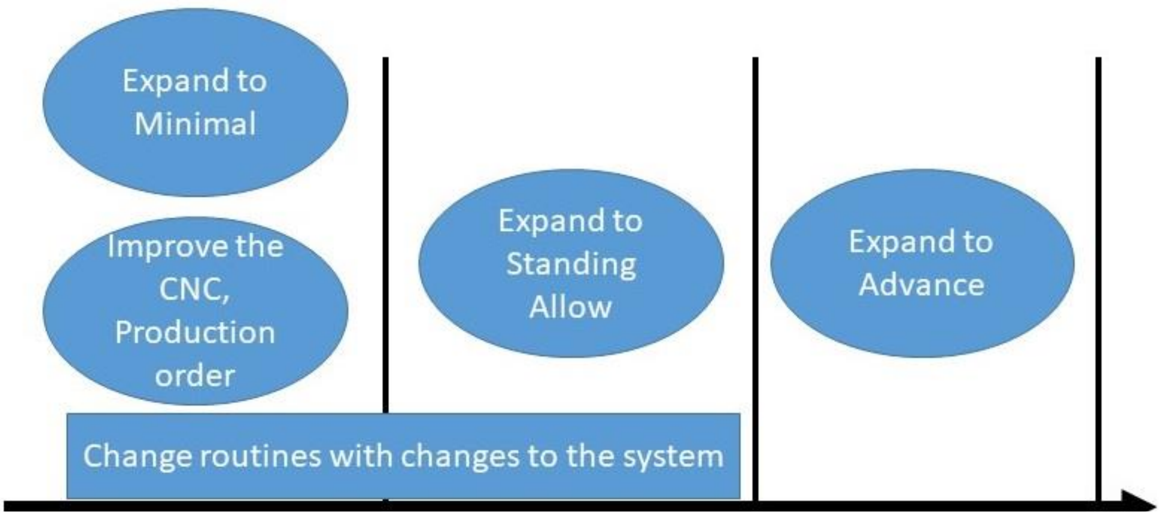

Figure 49: Strategy of implementation

11 Discussion

This chapter concludes the project by summarising the lessons learned and reflects on the result. It includes both pros and cons. It starts with an examination of the project execution and any problems in it. Suggestions on how to avoid them are then presented. The result is then analysed in how it represents industrial design engineering, how it fits in the subject and its relevance in a bigger context. It is followed by a conclusion on how well the project can answer the research questions and the objective. Finally, the recommendations to Martinsons is presented.

11.1 Project execution

This section covers a critical reflection regarding the execution of this thesis, based on the project plan and what transpired, and ends with lessons learned.

This thesis was carried out with Luleå as a base. It had both positive and negative aspects. The positive was that during the visits, there were bigger opportunities to ask the workers questions, as the visits were during less intense periods. It also allowed using the resources at LTUs academical recourses more. Both academical resources as having better access to the supervisor and other resources as other students to discuss with and other tools.

The negative aspects were that details about high demands periods could not be observed. Instead, the worst case was only discussed with the workers. The workers were also not involved as much as desired. Industrial design engineering focuses on the workers in the system. The plan was to use the entire week to do observations at Martinsons, but the reality was that some days were used to analyse the results from earlier days while the information was still fresh in mind. It could be solved by requesting an office at Martinsons so that the workers could be observed daily and involved when the demands were lower.

To have weekly updates with the contact at Martinsons was a good idea to solve the problems. In the emails, questions about details and requests for information were asked. Still, the users could not be involved in the methods, and the responsibility to gather information was placed on the supervisor at Martinsons.

However, this thesis has still been successful in its data gathering. The part missing is feedback on the concepts from the users. The concepts are all based on the data and opinions on the current system. By involving the workers in the process more, the result would have been improved. Industrial design engineering originates from the workers.

More focus could have been placed on the organisation and/or routines if the workers had been more involved in the creative phase. Most of the solutions involved an active change in the building. However, the major problems are in the building, which requires expansion. The routines have been changed, but that could have been better done with a larger team. The routines that would affect the situation mostly, production order and in the CNC, were outside the scope of the project.

The iterative work process was helpful to this project. As the project was advancing, more information was discovered about the subject, which changed some earlier assumption. For example, the project plan was changed three weeks into the project, as the original plan was focused on the CNC. Despite wasting almost one month in the beginning, the project was on time at the halftime point. Because of the lost time, it was expected to be tighter with time in the end. Without the iterative planning to recheck every step, time would have been sacrificed from other important subjects. The iterative planning allows for flexibility, as reality is always changing and "no plan survives first contact with reality" (Helmuth von Moltke, 1871, paraphrase).

11.2 Results

This section discusses the result of the project. It starts with an analysis on how the result fits as an example of industrial design engineering. The project's relevance for Martinsons is discussed and examined. Lastly, the effect on sustainability on a larger scale is discussed.

11.2.1 Positioning the result

It is the opinion of the author that industrial design engineering consists of three pillars: involve the workers, avoid risks and increase productivity. This project fulfils two of them, with the third one partially fulfilled. The major risks for the workers are in the packaging. While packing the littera, the workers are forced to bend and twist their backs, which cause large risks of MSD. By making the working height adjustable, these problems are solved. Still, the packaging is manual, which always holds a risk for MSD, but the objective is to optimise the workload, not replace it with inactive position, which also causes MSD (winkle, 1989). An automatic solution for the packaging could increase the productivity of a single worker by operating multiple stations at the same time. However, apart from a larger investment and more repetitive work, automation should be difficult because there are big variations in the packages, and some will still need a human hand.

Regarding the productivity, the largest problem is the rate the litteras arrive at the shipping. One hour, there can be almost no work, with several packages that need packaging the next one. In this project, the focus has been to move the littera to their station as quickly as possible to avoid a bottleneck in the sorting area.

Can the bottlenecks be completely avoided? Most likely not, because of two reasons: the main bottleneck is in the second CNC and the production order, which is outside the project scope. The second one is limited capacity in the shipping. Martinsons wants the press to decide the pace. In engineering terms, Martinsons wants to have a high flow efficiency (Modig & Åhlström, 2015).

However, as the production is an HMLV, the variations are high (Jina et al., 1997). In this system, the variations are in the workload and packaging times. At the same time, the resources in the shipping have high utilisation, a high resource efficiency. Summarised, because of the high resource efficiency and the variations the flow efficiency is restricted. Having both high flow and resource efficiency is hard. Modig & Åhlström believe that the focus should first be to improve the flows, then the utilisation of the machines (2015). To have a perfect flow the resources must be designed for the worst case: when many packages arrive at short intervals. However, only focusing on the flows is not reliable, if the machines are standing still large parts of the day, the capacity is wasted, just like if there as a bottleneck (Modig & Åhlström, 2015). With the proposed solution, both the flow and resource efficiency are high while still being ecumenically reliable (Modig & Åhlström, 2015).

Lastly, the last pillar, involving the workers, was partially fulfilled. During the data gathering and observations, the workers were observed and interviewed about their problems, and about any ideas that they had. In a perfect world, they would have been involved more in the creative phase, but they were unavailable because of the demand. As a result, the concepts were only influenced by one person. A creative process needs more than one opinion, especially opinions from the users.

11.2.2 Relevance

At the start of this project, the focus was on solving the problems with new routines. However, as time went on problems were reviled with regards to time and knowledge. As the subject became more and more clear, it was revealed that the routines in the shipping were good and that the problems regarding routines were outside the scope of the project. For example, the CNC causes extra work in the shipping, but Martinsons will deal with the mechanical problem themselves. The origin of most of the problems is that the current building was not designed to the current system. Changing routines could solve some of the problems, but not the real case. The real cause is the crane and the bottleneck it creates when many litteras arrive at the same time.

The new layout will solve the problems more efficiently but costs more than routines and standards, but the solution costs more. The costs are justified. The market for crosslam is high, ensuring a safe investment. Even with the high costs and interruptions to a strained situation, the investment justified. The first principle in lean is to have a long-time plan, even if the short-term situation is interrupted. The profit will increase because of the proposed solution.

11.2.3 Sustainability

This project has the potential to result in increased sustainability in the building market. Steel, for example, is a non-renewable resource and production of concrete releases significant amounts of CO2. Crosslam binds CO2 during its entire life cycle and has advantages to concrete and steel. Crosslam is lighter than steel, but has the same strengths, is easy to build with, costs less and creates more attractive buildings (Svenskt Trä 2017). Crosslam is even safer than steel in a fire, something that makes the life of firefighters safer (Svenskt Trä 2017). The demands for crosslam is increasing in Sweden and Europe, with an estimated demand of 600 000m3 by 2018.

This project will not single-handedly solve any of the problems in the world. However, this project will increase the supply of crosslam in Sweden; it will help to increase the recognition of crosslam. Crosslam might be a good step towards making our world more sustainable.

11.3 Conclusions

This chapter aims to answer the research questions formulated in the initial stages of the thesis, to confirm that all the objectives are solved and summarise the results. It ends with a description on how it solves the objective and aims.

How can the flows in the machines and shipping be improved?

There are two problems in the flows in the shipping. All movement uses the crane, and there is time wasted on smaller adjustments. The reality changed after the latest investment, and no change has been made to fix it. By dividing the flow of litteras and sawdust/cut-outs, more time is available for the littera. Moreover, by making the sorting area larger, more littera can be sorted and lifted at the same time, saving even more time. Also, by increasing the capacity in the shipping area, the flow efficiency can increase. Even with the variations in the workload, a high flow efficiency can be maintained, at the expense of having stations with no work (Modig & Åhlström, 2015).

The work with the adjustments is a larger problem as it both uses time and is a cause of ergonomic problems. The best case would be to adjust the CNC so that there are no remains to be removed. The alternative, if the CNC receives no change, is to have the remains removed automatically in a new machine or to do it in the packaging stations, so the litteras are not in the way of new litteras coming from the CNC. Bends in the back are avoided with an adjustable height at the stations.

What are the problems in the work environment and how can they be addressed?

The workers in the system are at risk of MSD, especially in the packaging. Because of the fixed heights, the worker must adjust to the station, resulting in a bent and twisted back. The walking in the stairs and up and down holes is also a risk, as it uses energy and has a small risk of falling. The situation could be avoided by making the packaging automatic. However, it would be an extensive investment, and it could change one risk to another, as the risks for MSD are high even if the physical demands are low. There needs to be a variation in the workload.

The temperature is also a problem. It exists in almost all industries with some gate. The temperature is not at the level of causing damages but lowers the comfort in the system. Few things can be done to avoid it, but if the draught can be avoided, the situation can be improved a lot. The first way is to lower the time the gate is open. In the current system, the gate is open for long times when the trolley is changed. The total time that the gate is open is low compared to the total. The proposed air lock avoids this problem entirely. The problem can be less extensive if the draught can be avoided from the gate entirely.

There are some smaller risks in the mental ergonomics. The work is mostly repetitive and with much pressure from the rest of the system. It has some risk of stress. The saving grace is that the social support of the group is high and the workers can receive support to handle the problems. However, the relation to the leaders needs to be improved. The workers need to feel valued in the workplace. Martinsons takes too long to address the current problems. The problems with the packaging should have been addressed within a week. Giving the workers more resources to deal with the problems, and implementing 5S thinking, the workers can feel like they matter in the system.

11.3.1 Project objective and aim

This project has the objective to improve the shipping to ensure that the press decides the pace, with the aim to present a new layout and routines for the shipping area.

With the proposed changes to the shipping, the flows of the packaging are improved. The flow efficiency will be increased, and the packaging will be faster, especially by reducing the need of the crane. These changes will remove the bottleneck in the shipping. The working conditions are improved by having adjustable tables and removing the stress of the bottleneck in the sorting area.

11.4 Recommendations to Martinson

The following is my, Viktor Berglund, recommendations to Martinsons Såg:

Martinsons should improve the CNC to avoid the extra adjustments needed in the sorting area

The remains and adjustments cost time in the shipping. By eliminating the wasted time, the workers will have more time for the packing of litteras.

Martinsons should oversee the production mix to achieve an even workload.

The uneven workload cases result in a lot of demand during a short time and long times without any work. The shipping can be improved by making the workload more even throughout the day.

Martinsons should expand the shipping to handle the new demand

Martinsons should expand and renovate the shipping using concept Standing Alone, followed by concept Advanced. The implementation should follow the proposed plan presented in Chapter 10.3. However, as the workers were not involved in the design process, Martinsons should review the concept and make any changes they believe are necessary. The workers need to be involved in the design process to use their knowledge. Implementation of the expansion should be as soon as possible, with the first steps taken in 2018. Martinsons should modify the concepts as they see fit.

Martinsons should oversee their routines regarding continuous improvement in the shipping

It took a long time to install the brakes on the wagon and raised workstations in the shipping, resulting in risks of MSD and unnecessary problems. Martinsons should strive for continuous improvement by giving the workers a larger possibility to solve their problems.

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Appendix 1: Survey

För att beskriva arbetsmiljön behöver jag få svar på dessa frågor. Alla svar är anonyma och kommer förvaras utan namn. Skriv gärna kommentarer vid svaren.

Bakgrundsinformation

Vilken del av fabriken arbetar du på?

Hur länge har du jobbat på arbetsplatsen?

Vilka är dina uppgifter?

Arbetsorganisation

1: Hur ofta känner du att du har du kontroll i ditt arbete?
Aldrig ***Alltid***
0--10

2: Hur stor frihet har du i att bestämma över ditt egna arbetstempo och/eller arbetsmetod?
Liten/Aldrig ***Stor/Alltid***
0--10

3: Känner du att du blir positivt utmanad i ditt arbete?
Aldrig ***Alltid***
0--10

4: Hur höga krav känner du på dig själv (från systemet, ledningen, kollegor osv) under ditt arbete?
Inga/små ***Stora***
0--10

5: Har du möjlighet att ta kortare paus, tex för att gå på toa, utan att det påverkar produktionen?
Ja Nej

6: Hur skulle du beskriva relationen mellan dig och dina arbetskollegor?
Dålig ***Mycket bra***
0--10

7: Hur skulle du beskriva relationen mellan dig och ledningen?
Dålig ***Mycket bra***
0--10

8: Hur ofta känner du att du inte har tillräckligt med tid i ditt arbete för att utföra det på ett bra sätt? Ringa in svar
Ett par gånger per dag Ett par gånger per vecka Mer sällan Aldrig

9: Behöver du arbeta ensam, utan kontakt med andra kollegor, under arbetsdagen?
Ja Nej

9a: Om ja: Hur ofta?

Fysisk belastning

10: Hur ofta känner du att arbetstempot blir viktigare än att arbeta med en bra arbetsposition?
Aldrig ***Alltid***
0--10

11: Då ditt skift avslutas, hur utmattad är du då?
Totalt slutkörd Knappt påverkad
0--10

12: Hur ofta arbetar du …
12a: Med böjd rygg?
Aldrig ***Alltid***
0--10

12b: I hukande position?
Aldrig ***Alltid***
0--10

12c: Under knähöjd medans du står?
Aldrig ***Alltid***
0--10

13: Är ljudnivån på din arbetsplats ett problem?
Ja Nej

13a: Om ja, på vilket sätt?

14: Har du problem att se vad du arbetet med på grund av att…
14a: ljuset är dåligt/ mörkt
Ja Nej

14b: du blir bländad
Ja Nej

14c: objektet är i en dålig vinkel
Ja Nej

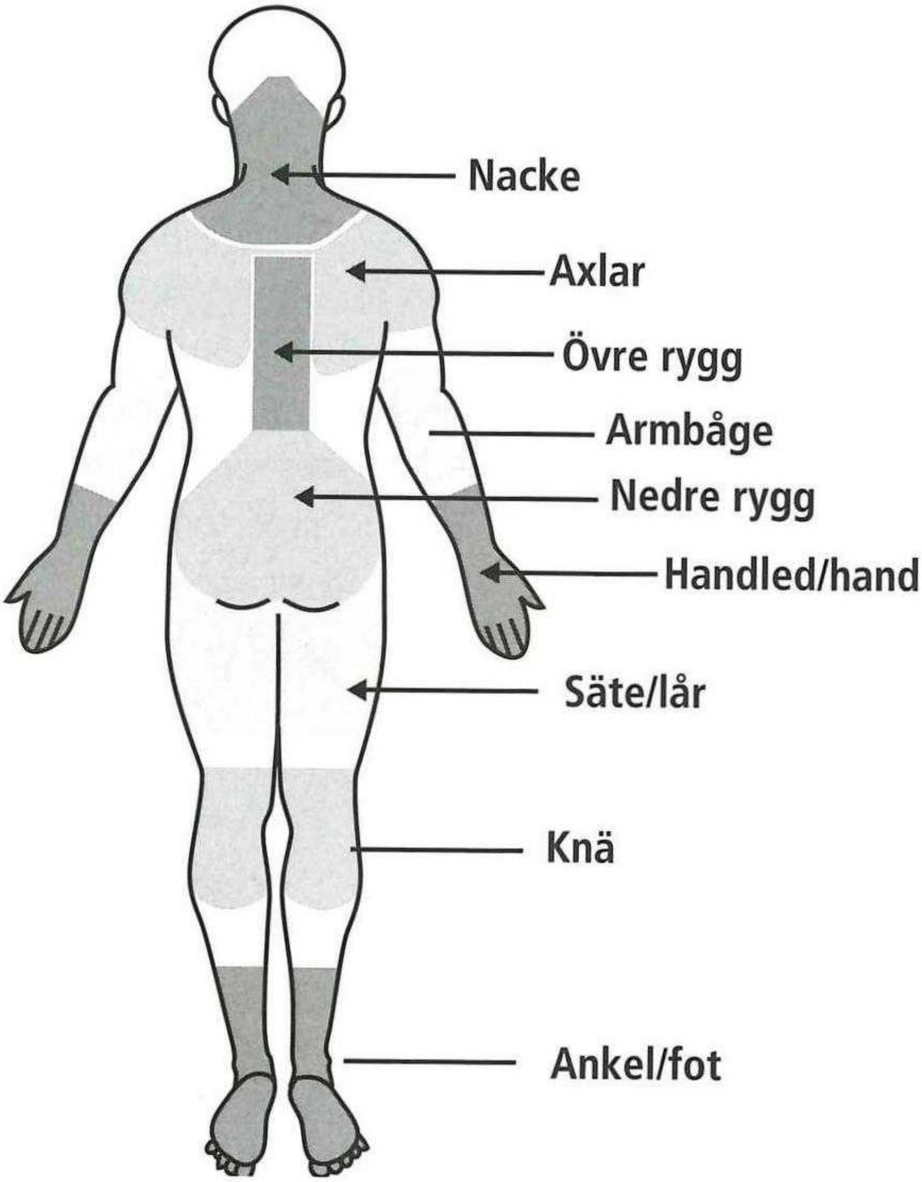
15: Har du fått utbildning eller instruktioner om hur du ska arbete med bra ergonomi?
Ja Nej

16: Har du smärtor som uppkommit från ditt arbete?
Ja Nej

16a: Om ja, från vilket/vilka moment tror du de kommer?

16b: Om ja, Vad har du fått för hjälp med dina besvär?

16c: Markera i bilden nedan vart du känner smärtor och har besvär.



Finns det något mer jag behöver veta kring arbetsmiljön?

Tack för att du deltog!

Appendix 2: Proximity analysis

Name		18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
CNC	**1**	3	5	5	5	3	3	3	3	3	3	3	3	5	3	3	5	5	
Quality control	**2**	3	3	3	3	3	3	3	3	3	3	3	4	5	3	4	3		
Plunder station	**3**	3	4	5	3	3	3	3	3	3	3	3	5	3	3	3			
Littera marking	**4**	3	3	3	3	3	3	3	3	3	3	3	5	5	4				
Label printer	**5**	3	3	3	3	5	4	4	3	3	3	3	5	5					
Computer	**6**	3	1	3	3	5	4	4	3	3	3	3	3						
Aces to crane	**7**	5	3	5	3	5	5	5	3	3	3	3							
Plastic storage	**8**	3	2	3	3	3	5	5	3	4	3								
Edge protections	**9**	3	2	3	3	3	5	5	3	4									
Planks	**10**	3	3	3	3	3	5	5	3										
Hand tools	**11**	5	2	3	5	3	4	4											
Workstation wall	**12**	4	2	2	4	4	4												
Workstation	**13**	4	2	2	4	4													
Packages removal	**14**	3	2	2	3														
Material storage	**15**	5	2	2															
Cut-outs handling	**16**	3	4																
Waste handling	**17**	3																	
EBH/repair station	**18**																		

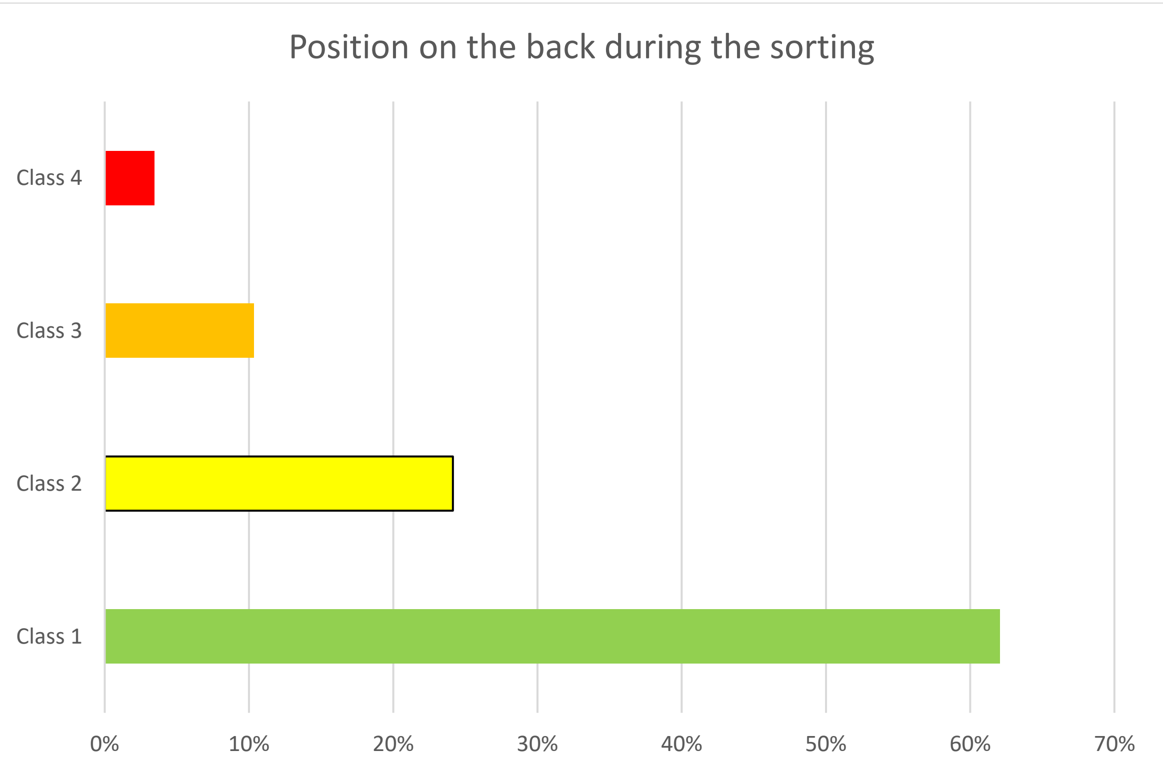
5	Critical	Must be fulfilled
4	Important	Shod be fulfilled
3	Neutral	Not important
2	Unvented	Should be avoided
1	Dangerous	Must be avoided

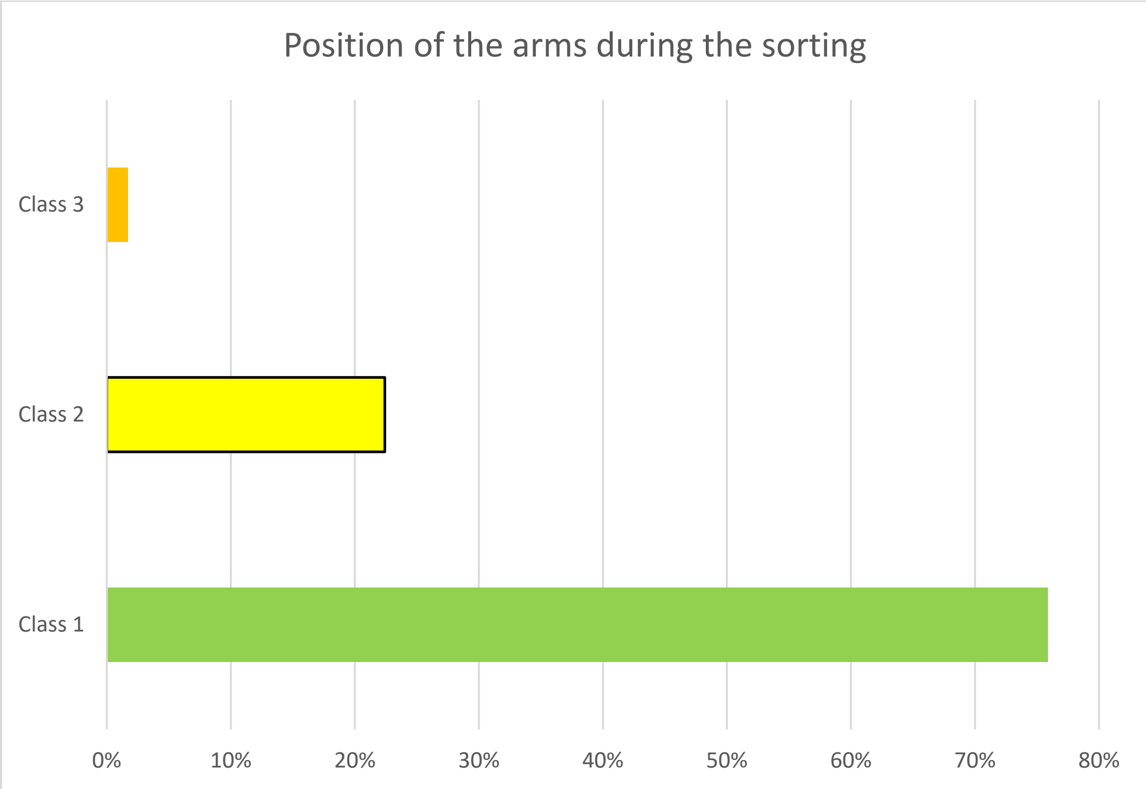
Appendix 3: Ergonomic analysis of Sorting area

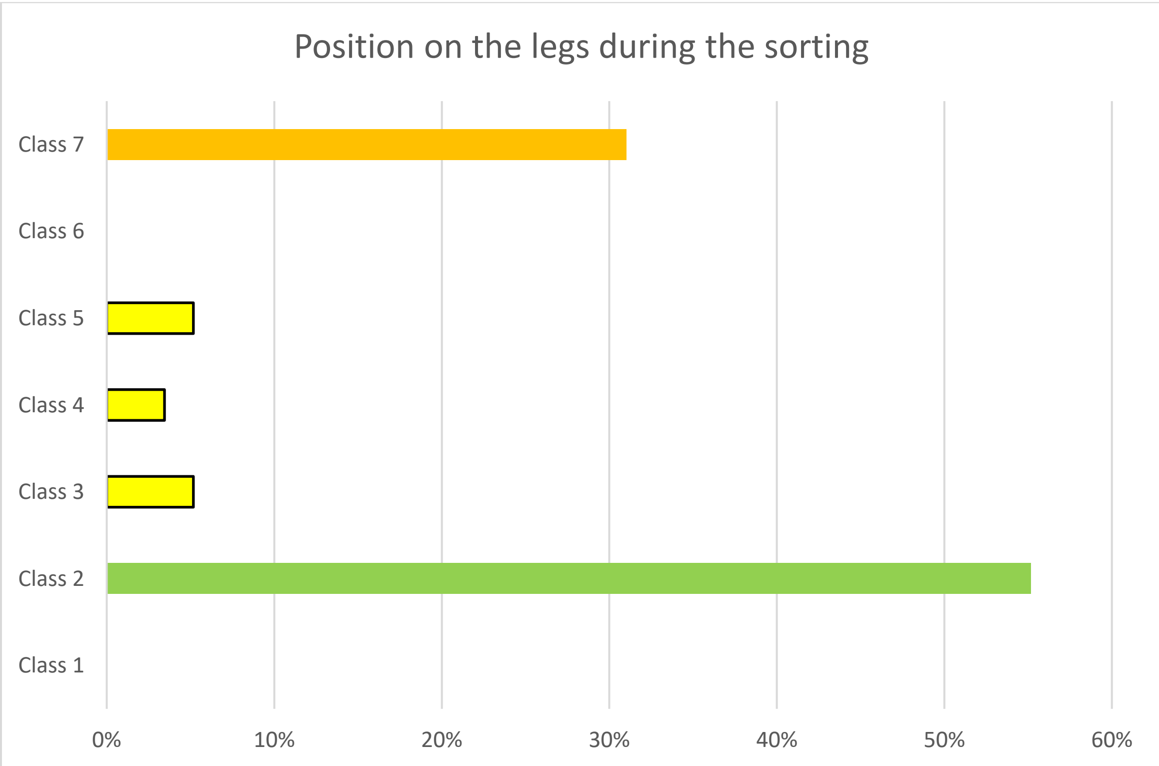
Position	***ID***	***Back***	***Arms***	***Legs***	***Load***	**Summed**	***Neck***
1	1	3	1	2	1	**1**	5
2	1	3	1	2	1	**1**	2
3	1	2	2	7	1	**2**	2
4	1	3	1	2	1	**1**	2
5	1	1	1	7	1	**1**	1
6	1	3	1	2	1	**1**	1
7	1	3	1	2	1	**1**	1
8	1	3	1	7	1	**1**	2
9	1	1	2	7	1	**1**	1
10	2	1	1	3	1	**1**	2
11	2	1	2	2	1	**1**	1
12	2	1	2	2	1	**1**	2
13	3	2	1	2	1	**2**	2
14	3	2	1	3	1	**2**	2
15	3	2	1	5	1	**3**	2
16	3	4	1	2	1	**2**	5
17	3	2	1	2	1	**2**	1
18	3	2	1	2	1	**2**	1
19	3	2	1	3	1	**2**	4
20	4	2	1	7	1	**2**	1
21	2	2	1	4	1	**3**	1
22	5	1	1	2	1	**1**	1
23	4	1	1	7	1	**1**	1
24	4	1	1	7	1	**1**	1
25	5	1	1	2	1	**1**	2
26	5	1	1	2	1	**1**	1
27	4	1	1	7	1	**1**	2
28	6	1	1	2	1	**1**	1
29	6	1	1	2	1	**1**	1
30	6	1	1	2	1	**1**	1
31	4	1	1	7	1	**1**	1
32	4	1	1	7	1	**1**	2
33	4	1	1	7	1	**1**	2
34	7	2	1	7	2	**3**	4
35	7	1	1	2	1	**1**	1
36	7	1	2	2	1	**1**	1

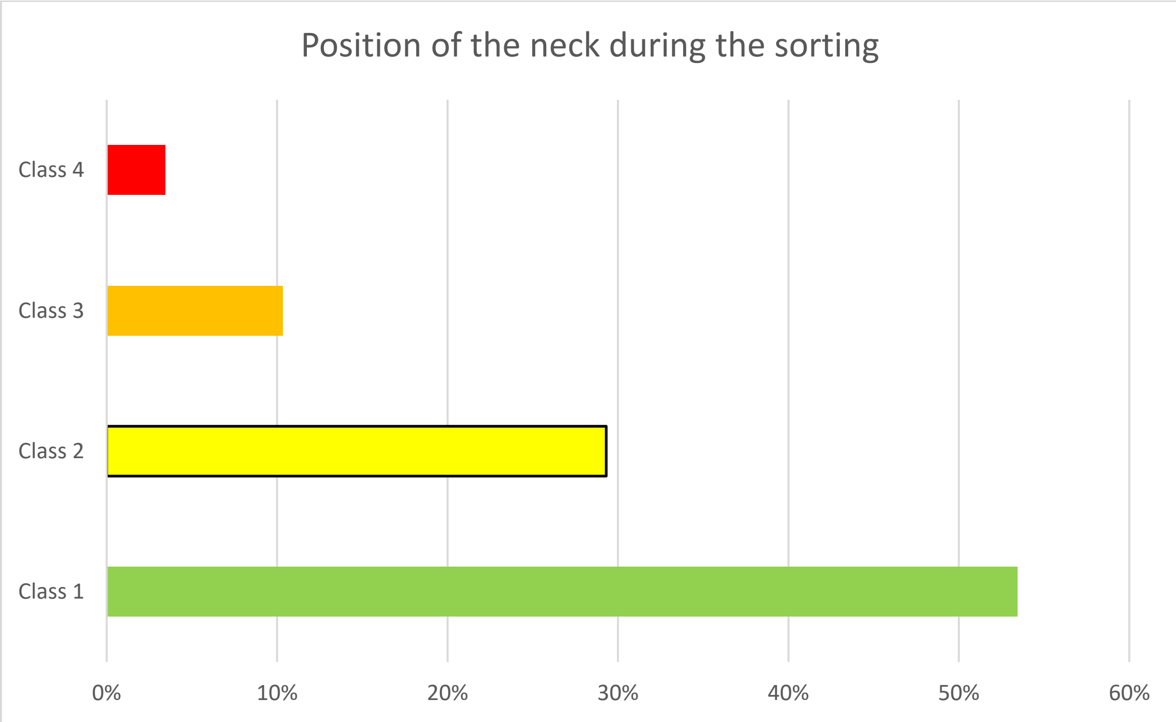
ID Key	
Remove sawdust	1
Tools handling	2
Remains removal	3
waking	4
Organizing	5
lifting with crane	6
controlling crane	7
Pushing wagon	8

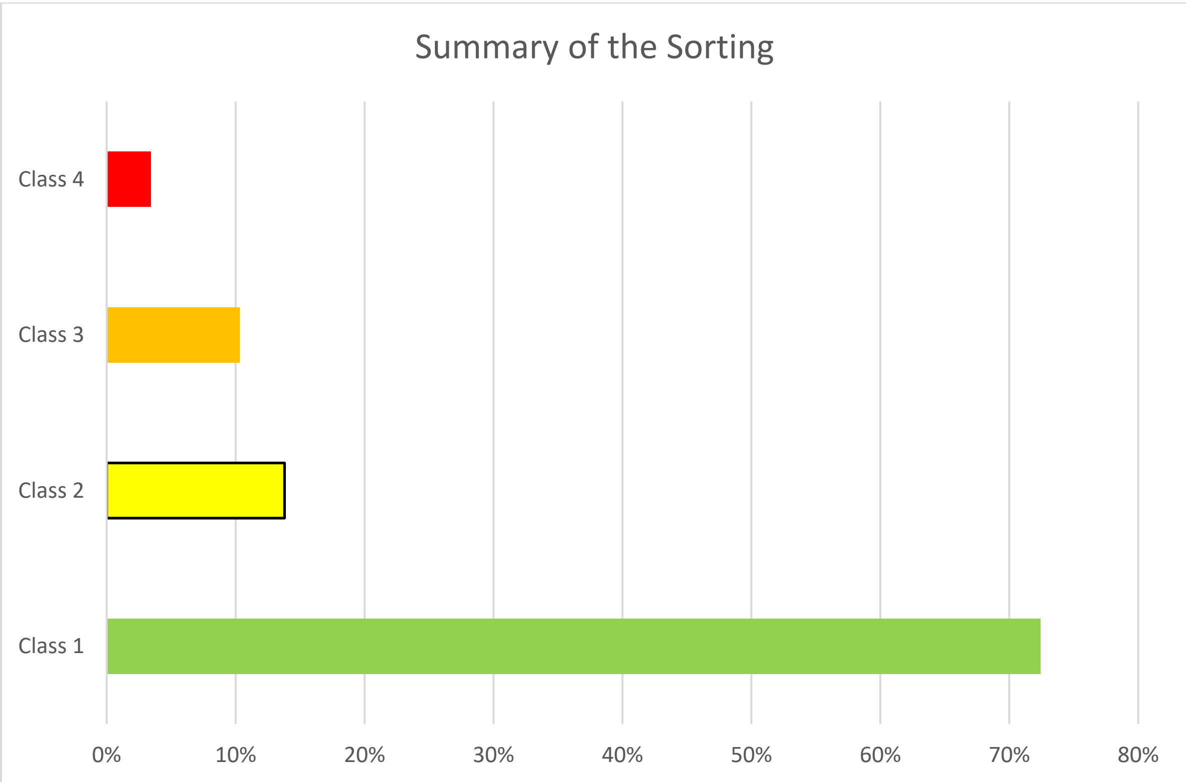
37	7	1	1	2	1	**1**	1
38	7	1	2	2	1	**1**	1
39	7	1	2	2	1	**1**	1
40	8	2	1	7	2	**3**	3
41	8	2	1	7	2	**3**	3
42	8	1	1	7	1	**1**	3
43	7	1	1	2	1	**1**	2
44	7	1	1	2	1	**1**	2
45	7	1	1	2	1	**1**	1
46	7	1	2	2	1	**1**	1
47	8	2	2	5	2	**4**	3
48	8	1	3	2	2	**1**	3
49	8	1	1	7	2	**1**	2
50	5	1	1	7	1	**1**	3
51	5	1	2	2	1	**1**	1
52	5	1	2	2	1	**1**	1
53	6	2	2	4	1	**3**	1
54	6	1	1	7	1	**1**	1
55	6	4	2	5	1	**4**	2
56	5	1	1	2	1	**1**	1
57	5	1	1	2	1	**1**	1
58	5	1	1	2	1	**1**	1




Position of the arms during the sorting
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%
70%
80%


Position on the legs during the sorting
Class 7
Class 6
Class 5
Class 4
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%


Position of the neck during the sorting
Class 4
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%


Summary of the Sorting
Class 4
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%
70%
80%

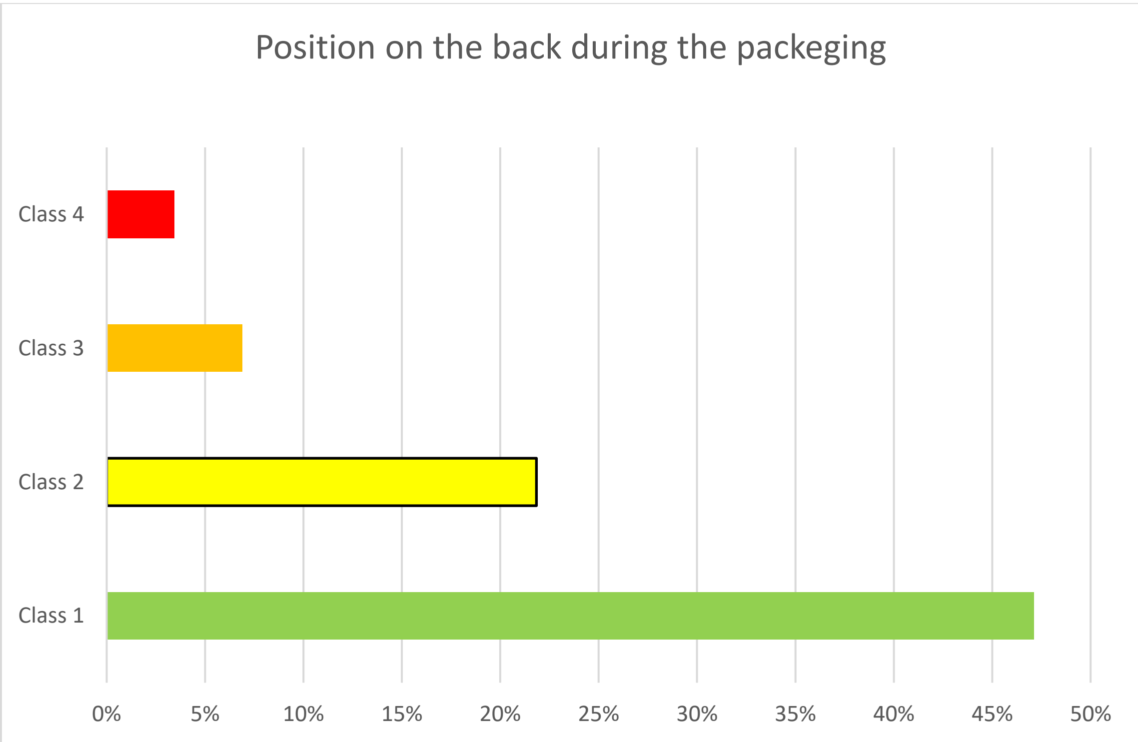
Appendix 4: Ergonomic analysis of Packaging area

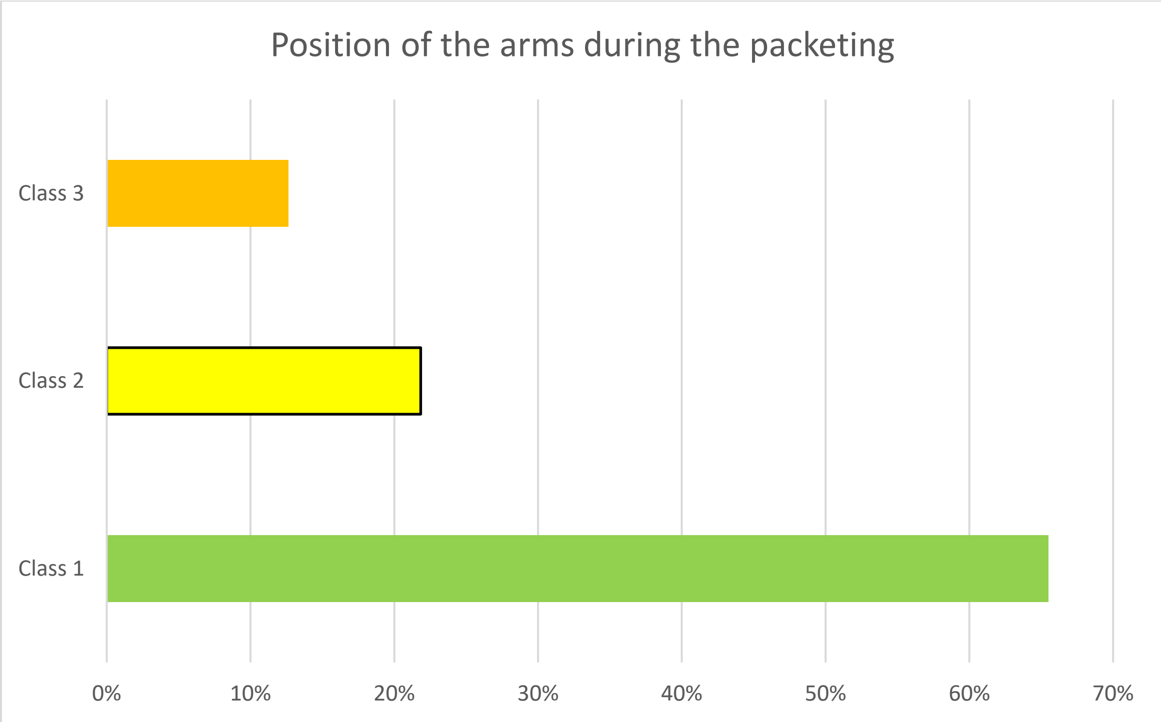
ID	Back	Arms	Legs	Load	Summed	Neck
11	1	1	7	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	2	1	2	1	2	2
2	1	1	2	1	1	1
2	1	1	2	1	1	1
2	1	2	2	1	1	1
2	2	2	3	1	2	4
3	1	1	2	1	1	1
3	1	1	2	1	1	1
3	2	1	7	1	2	1
11	2	3	2	1	2	2
3	2	3	2	1	2	1
3	2	3	2	1	2	3
11	1	1	7	1	1	1
3	2	1	4	1	3	4
3	1	3	2	1	1	1
3	1	1	2	1	1	1
3	2	1	2	1	2	2
3	1	2	2	1	1	1
3	2	1	2	1	2	1
3	1	1	2	1	1	1
3	3	1	2	1	1	5
3	2	1	2	1	2	1
3	3	1	2	1	1	5
3	2	1	5	1	3	4
3	1	3	2	1	1	2
3	1	2	7	1	1	5
3	1	2	2	1	1	4
11	2	1	2	1	2	1
4	2	1	2	2	2	4
2	2	1	2	1	2	1
2	1	1	7	1	1	1
2	1	2	2	1	1	3
2	2	1	7	2	3	2

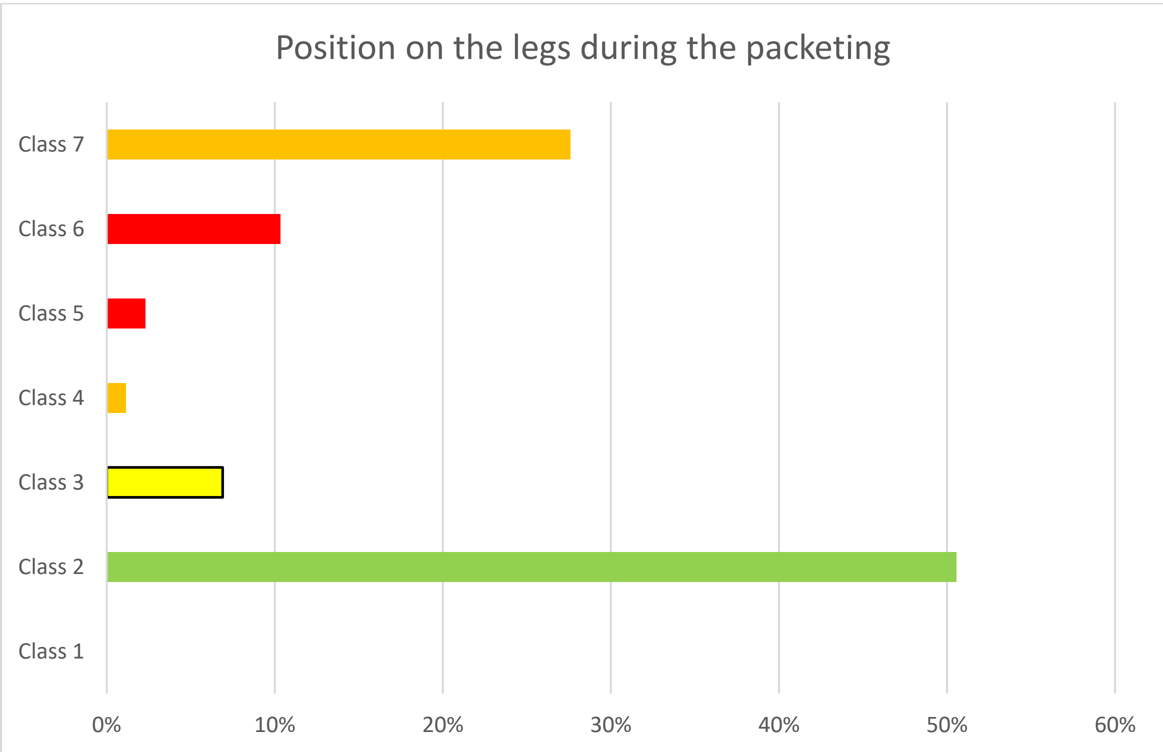
ID Key	
Placing littera	1
Placing sheet	2
Attaching sheet	3
pilling chart	4
Fetching/ adjusting tool	5
Attaching cover sheet	6
Cutting sheet	7
Fetching edges	8
Placing straps	9
Attaching nots	10
Waking	11

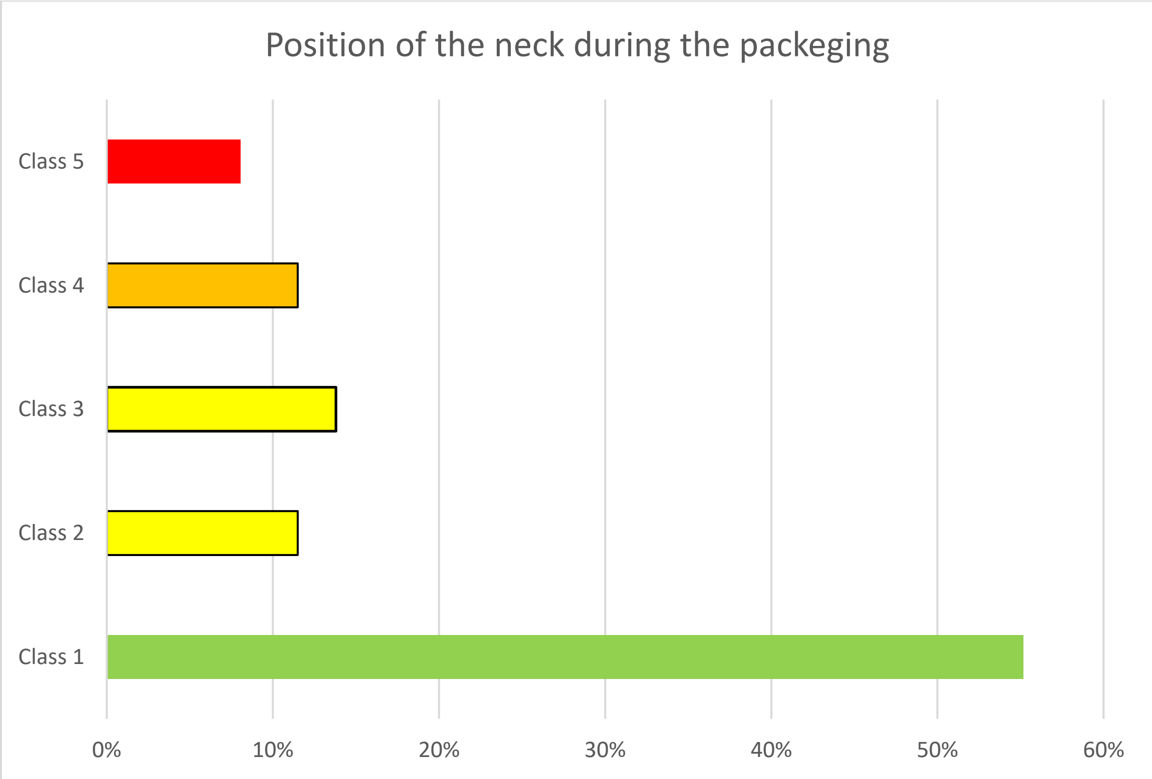
2	2	1	2	1	2	3
2	2	1	2	1	2	4
11	1	1	7	1	1	1
2	1	3	2	1	1	2
2	1	3	2	1	1	1
5	1	1	2	1	1	1
11	1	1	7	1	1	3
11	1	1	2	1	1	1
5	1	1	2	1	1	1
6	1	1	7	1	1	1
6	1	1	2	1	1	1
6	2	1	3	1	2	4
7	3	2	3	1	1	1
7	3	2	3	1	1	1
6	1	3	7	1	1	4
6	2	1	7	1	2	3
6	2	1	7	1	2	3
6	2	1	7	1	2	1
6	2	1	7	1	2	1
6	4	2	7	1	2	1
6	2	1	7	1	2	1
6	4	2	7	1	2	1
6	1	1	7	1	1	1
6	4	2	7	1	2	1
6	1	2	7	1	1	1
8	3	2	2	1	1	1
8	1	1	2	1	1	1
8	1	2	2	1	1	5
8	3	3	2	1	1	1
8	2	1	6	1	2	2
8	2	1	6	1	2	3
8	1	2	7	1	1	5
8	2	1	6	1	2	1
8	2	1	6	1	2	1
3	1	1	7	1	1	1
4	1	1	7	2	1	1
9	1	3	7	1	1	5
9	1	2	6	1	1	3
9	2	1	6	1	2	1
9	2	1	6	1	2	5
9	2	1	5	1	3	4
9	1	2	2	1	1	2

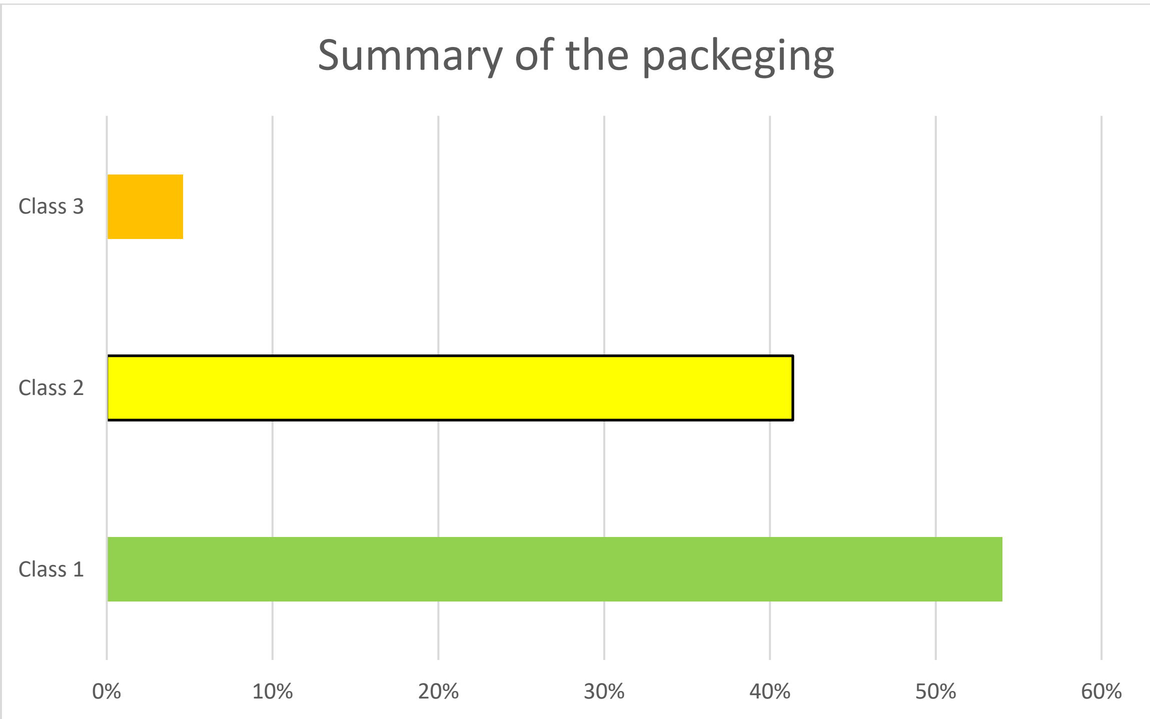
9	2	2	2	1	2	3
9	2	1	6	1	2	3
9	2	1	6	1	2	3
11	1	1	7	1	1	2
10	1	3	2	1	1	1
10	1	2	2	1	1	2
10	2	1	2	1	2	4
10	2	1	2	1	2	1
10	2	1	3	1	2	3
10	2	1	3	1	2	1




Position of the arms during the packeting
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%
70%


Position on the legs during the packeting
Class 7
Class 6
Class 5
Class 4
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%


Position of the neck during the packeging
Class 5
Class 4
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%


Summary of the packeging
Class 3
Class 2
Class 1
0%
10%
20%
30%
40%
50%
60%

Appendix 5: Answers from the survey

	Total	Gluing	Shipping	CNC	Shipping /CNC
Time (Months)	7.5	7.7	4.7	18	6.7
1	7.6	7.7	7	8	8
2	5.5	5	6.8	5	4.7
3	6.4	5.3	6.7	8	6.7
4	8.3	8	8.7	10	7.7
5	Yes	Yes	Yes	Yes	Yes
6	9.0	9.3	8.3	8	9.7
7	8.0	6.7	7	10	9.7
8	w: 6. D:1. R:3	W:2 R:1	W:2 R:1	Weekly	W:1. D:1.R:1
9	No	No	No	Yes	No
9a				During lunch	
10	7.0	7.7	6	7	7.3
11	5.2	6	5.5	4	4.3
12a	6.5	4	9	3	7.7
12b	5.5	3	7.3	3	7
12c	4.9	3.3	7.5	NA	4
13	Yes	Yes	Yes	No	Ja:2 Sometimes:1
14a	Y:1 N:9	No	No	No	J:1. N:2
14b	No	No	No	No	No
14c	Y:1 N:9	Y:1 N:2	No	No	No
15	Y:1. N:8. Nja 1	No	N:2 Nja:1	No	J:1. N:2
16	Y:5 N:5	Y:2 N:1	Y:2. N:2	No	J:2.N:1
16a		Stranding and Walking on the hard floor	Backs and knee	NA	Heavy lifting. objects far from the body
16b		NA	Nothing	NA	Nothing uses medicines
Neck	2		1		1
Shoulders	5	1	1		3
Upper back	4	1	1		2
Lower back	4	1	1		2
Gluteus / thigh					
Knee	2		1	1	1
Foots	3			1	2
Comments					It is dusty

Appendix 6: Grading key for the specification

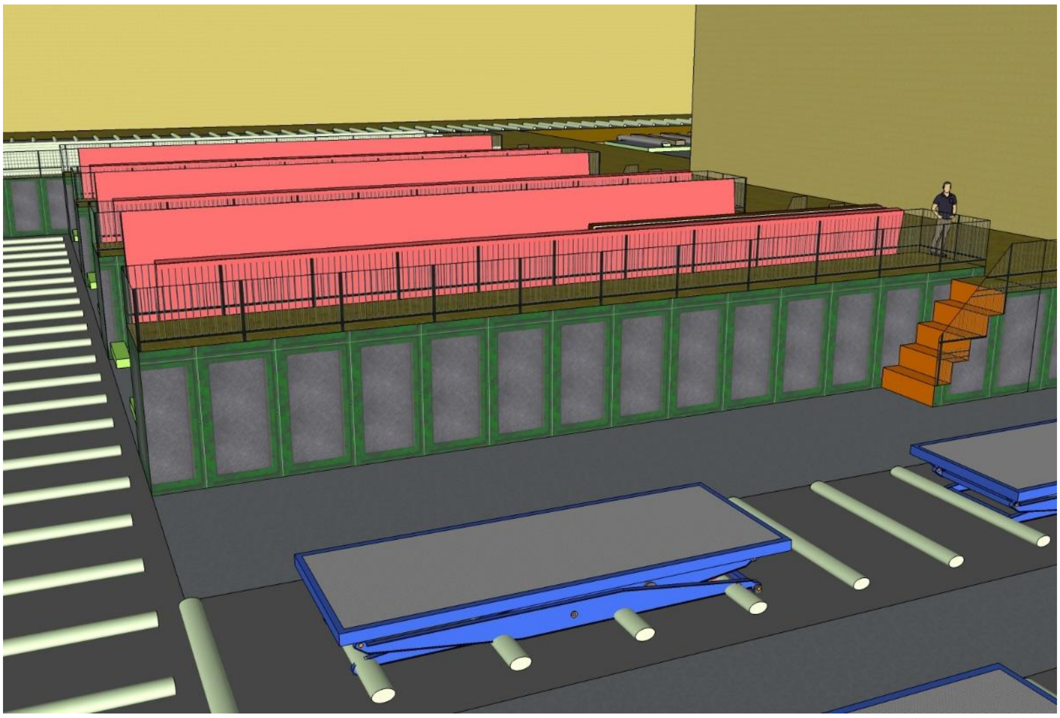
Specification	*Grading*
Minimise lifting required	3: All handling requires the crane
	6: There is no lifting with the cranes at all
Prevent physical damage to the workers	3: The workers are exposed to accidents daily
	6: The workers are protected from all risks and will never complain
Ensure the temperature is in the neutral zone	3: There are a door or gate always open to the outside
	6: The temperature will never be affected by the gate and production
Ensure that the Psychosocial working environment	3: The worker are guaranteed to developed mental problems
	6: The worker's mental condition is improved thanks to their work
Improving the handling of Littera and packages	3: The flows are interrupted several times an hour thanks to the litteras.
	6: There are never any problems in the handling of the litteras and packages.
Prevent the secondary flows from interrupting the litteras	3: The flow of sawdust and cut-outs affects the packaging and workers at all time.
	6: The handling of sawdust cut-outs requires no workers and is not affecting the environment in the shipping
Make a recovery and use of space faster and easier	3: The recovery is slow, and a lot of space has now value
	6: The packages removal is automatic, and space is optimally used
Allow flexibility in the packaging	3: If any litteras arrives late the packaging must stop
	6: Thera are never any problems if a littera arrives later than the others
Make the packaging of walls faster	3: There is no packaging of walls
	6: The packaging of walls is fully automatic or easily handled with one worker
Expansion required	3: The production can be maintained during the expansion
	6: The expansion requires minor and will not affect the production

Appendix 7: Detailed Figure of final concepts

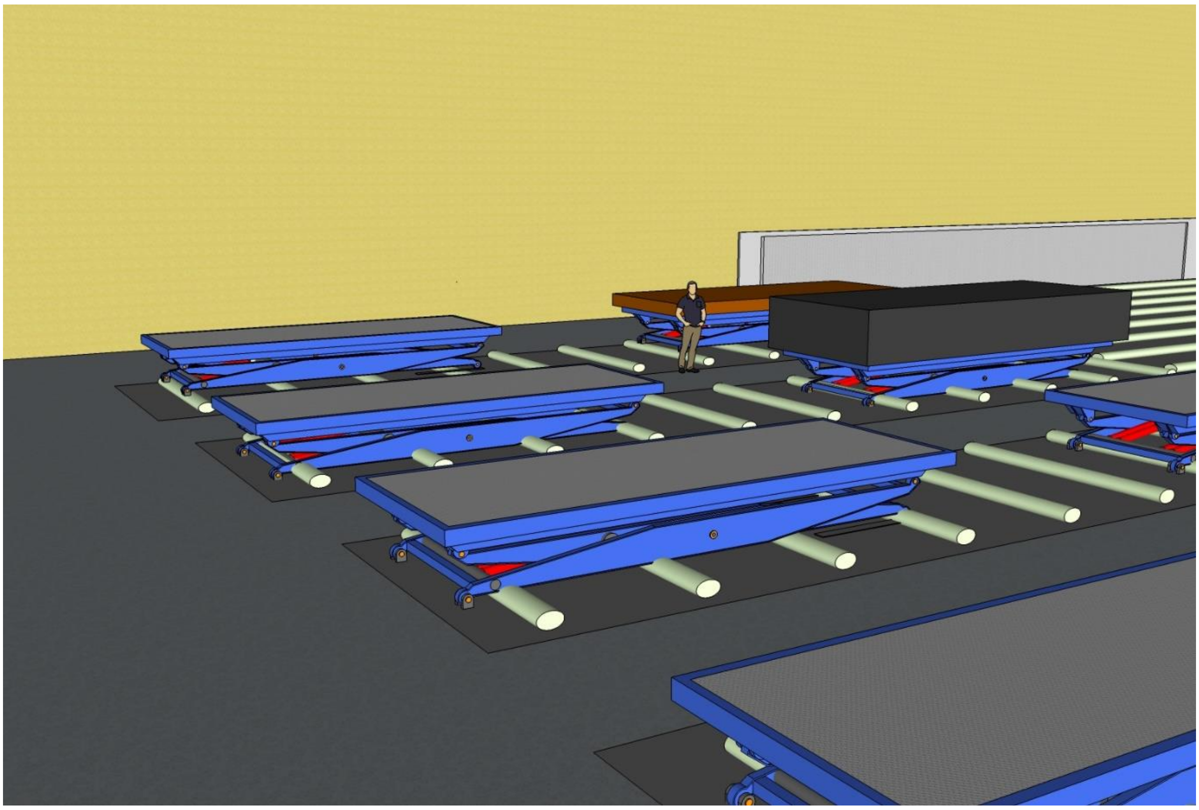
Standing Alone

The New EBH

The standing station, seen from the ground floor

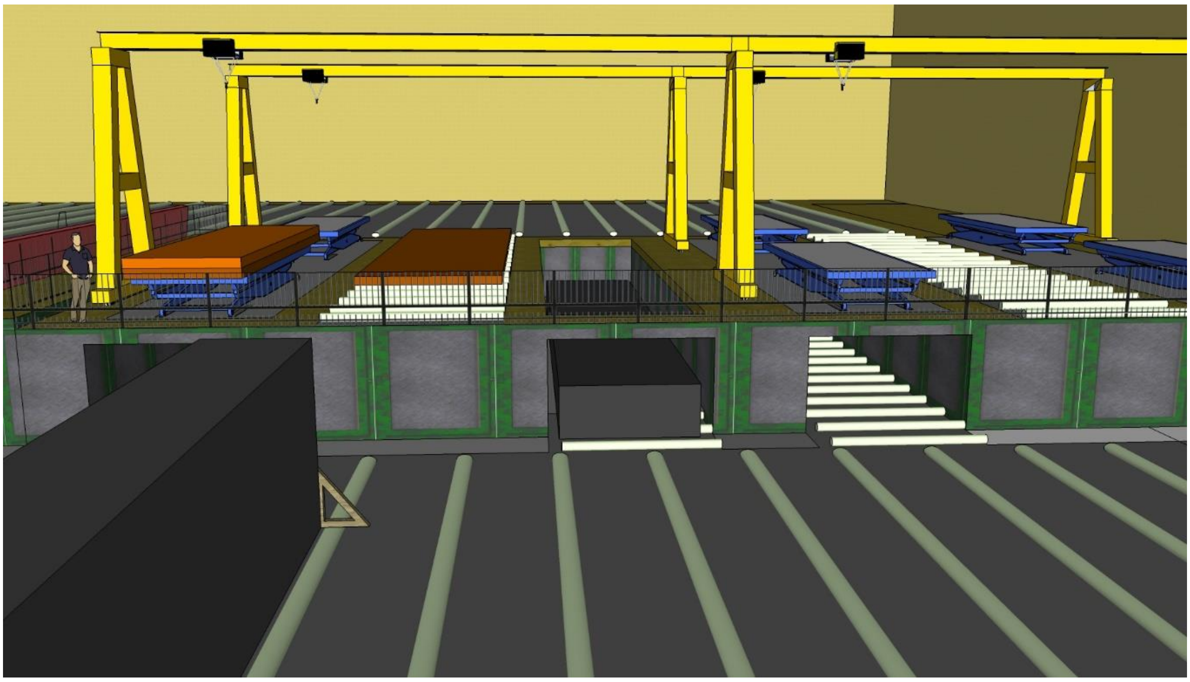


Standard packaging stations, seen from the standing stations

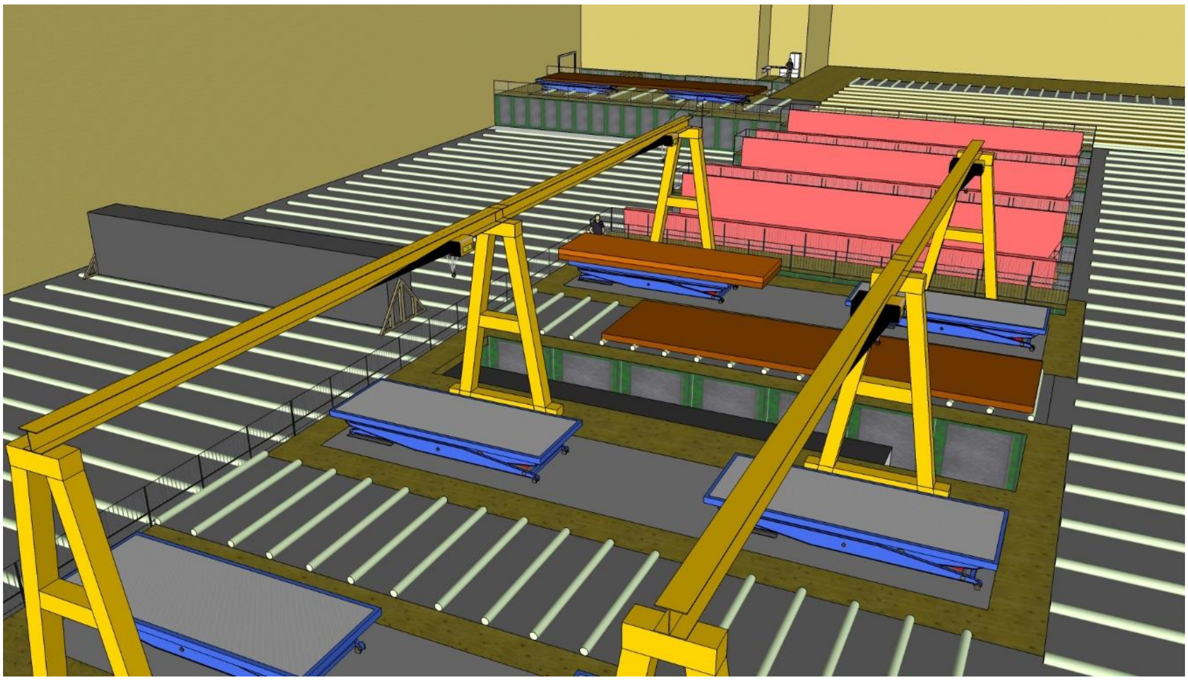


Advance

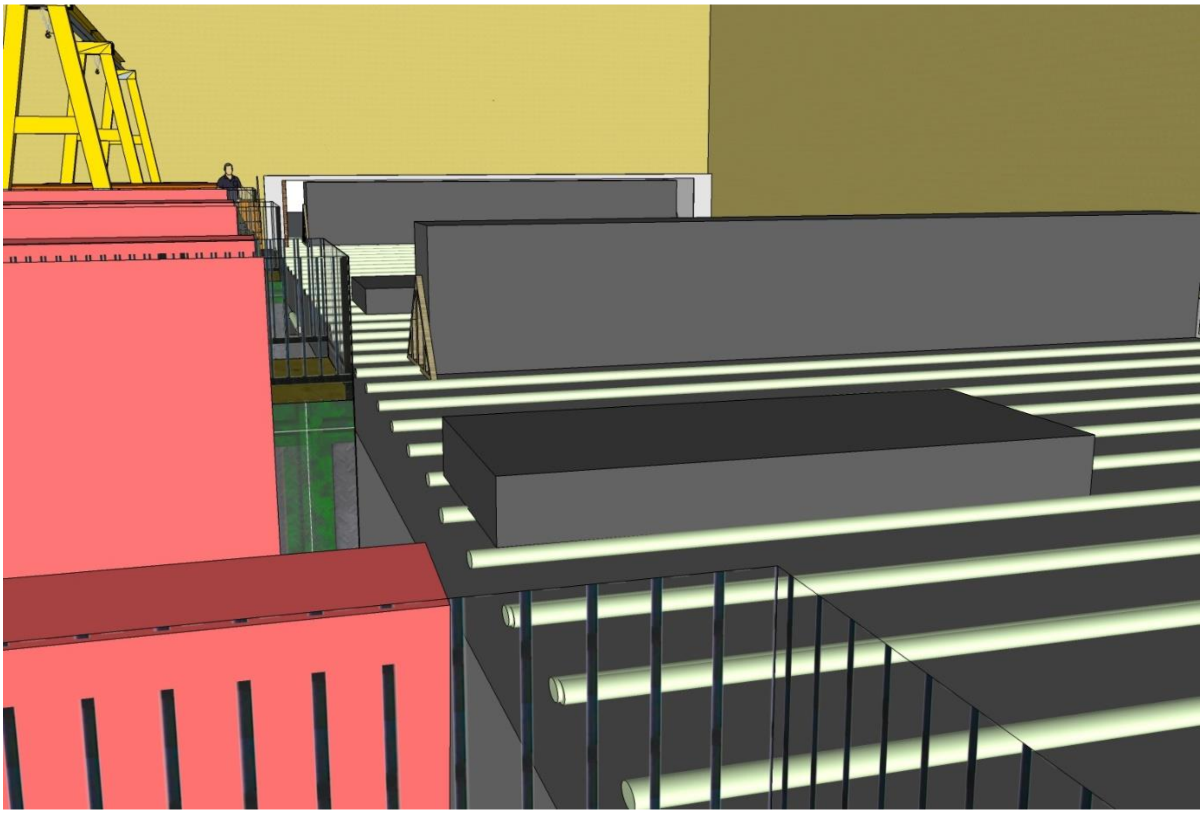
Packages being moved through the shipping



The entire Shipping in Advance



Out-loading of packages



Appendix 8: Economic Calculations

Table A: Calculate the cost of expansion

Cost/ compartment	1 371 645,45 kr
Only workshop	- 251 700,00 kr
No partition	-148 100,00 kr
Modified cost/ compartment	971 845,45 kr
Cost m^2	6 310,68 kr

Table B: Calculate the cost of Cranes

Subject	***Cost/m***	***Total Cost***
Expanding existing	3000skr/m	30 000skr
Smale one of the out loading	2500skr/m	25 000
Portal for Advance stations	500000skr/ st	1000000skr

Table C: Cannulating the cost for the expansion

Standing	**Cost (TSEK)**	**Advance**	**Cost (TSEK)**
Expansion	10 690	*Expansion*	7 257
Standard working stations	1 100	Lifts for packages	880
Standing stations	300	Cranes at stations	1 000
Crane in the EBH	25		
Expanded crane	30		
Total cost	**12 145**		**9 137**

Payoff Time Calculation

4 Years

	-2	-1	0	1	2
Costs for expansion	- 12 145 300,00 kr		- 9 137 287,49 kr		
Profit required each month	**254 000,00 kr**				
Profit each year	3 048 000,00 kr	3 048 000,00 kr	3 048 000,00 kr	3 048 000,00 kr	3 048 000,00 kr
Accumulated income	- 9 097 300,00 kr	- 6 049 300,00 kr	- 12 138 587,49 kr	- 9 090 587,49 kr	- 6 042 587,49 kr

	3	**4**
Profit each year	3 048 000,00 kr	**3 048 000,00 kr**
Accumulated income	- 2 994 587,49 kr	**53 412,51 kr**

6 Years

	-2	-1	0	1	2
Costs for expansion	- 12 145 300,00 kr		- 9 137 287,49 kr		
Profit required each month	**198 000,00 kr**				
Profit each year	2 376 000,00 kr	2 376 000,00 kr	2 376 000,00 kr	2 376 000,00 kr	2 376 000,00 kr
Accumulated income	- 9 769 300,00 kr	- 7 393 300,00 kr	- 14 154 587,49 kr	- 11 778 587,49 kr	- 9 402 587,49 kr

	3	4	5	**6**
Profit each year	2 376 000,00 kr	2 376 000,00 kr	2 376 000,00 kr	**2 376 000,00 kr**
Accumulated income	- 7 026 587,49 kr	- 4 650 587,49 kr	- 2 274 587,49 kr	101 412,51 kr

7 Years

	-2	-1	0	1	2
Costs for expansion	- 12 145 300,00 kr		- 9 137 287,49 kr		
Profit required each month	**178 000,00 kr**				
Profit each year	2 136 000,00 kr	2 136 000,00 kr	2 136 000,00 kr	2 136 000,00 kr	2 136 000,00 kr
Accumulated income	- 10 009 300,00 kr	- 7 873 300,00 kr	- 14 874 587,49 kr	- 12 738 587,49 kr	- 10 602 587,49 kr

	3	4	5	6	**7**
Profit each year	2 136 000,00 kr	2 136 000,00 kr	2 136 000,00 kr	2 136 000,00 kr	**2 136 000,00 kr**
Accumulated income	- 8 466 587,49 kr	- 6 330 587,49 kr	- 4 194 587,49 kr	- 2 058 587,49 kr	77 412,51 kr

10 Years

	-2	-1	0	1	2
Costs for expansion	- 12 145 300,00 kr		- 9 137 287,49 kr		
Profit required each month	**137 000,00 kr**				
Profit each year	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr
Accumulated income	- 10 501 300,00 kr	- 8 857 300,00 kr	- 16 350 587,49 kr	- 14 706 587,49 kr	- 13 062 587,49 kr

	3	4	5	6	**7**
Profit each year	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr	1 644 000,00 kr
Accumulated income	- 11 418 587,49 kr	- 9 774 587,49 kr	- 8 130 587,49 kr	- 6 486 587,49 kr	- 4 842 587,49 kr

	8	9	**10**
Profit each year	1 644 000,00 kr	1 644 000,00 kr	**1 644 000,00 kr**
Accumulated income	- 3 198 587,49 kr	- 1 554 587,49 kr	**89 412,51 kr**