Improving the labour utilisation in the product finishing process

Ilse Grootte Bromhaar
S2146541
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University of Twente supervisor: dr. P. C. Schuur

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Author:
Ilse Grootte Bromhaar
Bachelor Industrial Engineering and Management

Company:

Berrry Promens Deventer BV.

Zweedsestraat 10

7481BG, Deventer

The Netherlands

University of Twente:

University of Twente

Drienerlolaan 5

7552 NB, Enschede

The Netherlands

Supervisor Promens:
Dennis Oosterhuis

1st supervisor University of Twente:

Dr. P.C. Schuur

2nd supervisor University of Twente:

Dr. I. Seyran Topan

Preface

Dear reader,

In front of you lies my thesis assignment, written for my bachelor Industrial engineering and Management at the University of Twente. The research is performed at the company Berry Promens, located in Deventer. Even in this strange times, I got the opportunity to perform my research there and developed myself, for which I am very thankful.

First, I want to thank my company supervisor Dennis Oosterhuis for passing on his experience and guiding me throughout the process. The received feedback was of good use and he was always available to answer any questions I had. The colleagues in the office welcomed me and guided me when getting to know the company, for which I am thankful as well.

A big thanks goes to the employees in the production hall, where I performed my study. They know a lot about their work and tell enthusiastic about it. Every question I had was answered very thoroughly and they gave a lot of extra information that turned out as being very useful. They always had time or made time for me, opened up to me and gave me good insights in the production process. I really liked working with them and it was always fun to have a talk.

I would like to thank Peter Schuur, my supervisor from the University of Twente. His feedback and support guided me in the process of writing this thesis. I also want to thank Ipek Seyran Topan for being my second supervisor and giving the extra support.

Besides this, I would like to thank my friends and family with their support and sharing their thoughts on this thesis. I am thankful to have really great housemates, who were always there when I came home after a busy day. In case I was stuck on something, they always took time to listen and thought along to get to a solution. Together with them, there is always a lot of fun in the house and space to relax, which kept me motivated during the past six months.

This thesis is created based on a combination of theoretical and practical insights. I would like to thank all the teachers from the study Industrial Engineering for sharing their knowledge over the past three years. Next I would like to thank my colleagues from my part-time job, where I have developed quite some skills over the past five years, which were very useful when executing this study.

Management summary

The management summary has six sections. It introduces the problem introduction, whereafter it states the research approach and the used theory. The findings section provides an analysis of the current situation, whereafter the results summarize the outcome of several solutions. The recommendation involves the advised solution.

Problem introduction

The company Promens produces plastic hollow products with the use of rotational moulding. Some of these products are water tanks for in a caravan, RV or wind turbine. The production process has four workstations: (i) the rotational moulding machine, (ii) the finishing tables (AWA), (iii), the finishing robots and (iv) the packaging section. After the products come out of the machine, finishing activities such as trimming, cleaning and assembling, are undertaken at the AWA tables and at the robots to make the product customer-ready. In the current situation, each rotational moulding machine has one employee performing these activities. The company focusses on having a one-piece flow process, to ensure a high quality of their products and a low product rejection rate. The current problem is that the company has the feeling that they are not making optimal use of their employees. There is not enough work coming from one machine to have one handler next to it and properly use his labour time. To make funded decisions, it requires more data of the current activities. The research question that will be answered is: *"What improvements can be made in the production process of Promens in order to increase the labour utilisation of the employees?"*

Research approach

The Systematic Handling Analysis (SHA) is the main theoretical perspective for this research. The determined step-wise approach guides in establishing the choice for handling equipment. At first, the product variability and employee-performed actions are investigated in order to determine the required production time for each process step. Depending on a high or low product variability, a different handling tactic is selected. Together with the available production data, the overall required time per activity at the different workstations is determined. Reallocation of the tasks requires a different flow of products, for which the SHA in combination with found theory provides several solutions. The next steps of the SHA involve determining the investment costs and choosing the best handling methods, all resulting in a new division of tasks, a new level of labour utilisation and the implementation of handling equipment. The different steps were accomplished by performing several interviews, using existing data and gathering new data by observing the production hall.

Theory

Theoretical insights for decreasing walking distance and a choice for a type of handling equipment are gathered and applied. An understanding of the production of plastic hollow products is required. The lean principle with a one-piece flow tactic is discussed, resulting in having no stock in-between workstations. The literature study focusses on theoretical principles with regards to decreasing the walking paths. These involve: (i) no walking paths crossing each other, (ii) an L-, U- or parallel shaped production process, (iii) interchanging the tasks at workstations and (iv) the use of conveyor belts. The SHA guides in determining the type of handling method, based on the flow intensity and the travel distance of the products. Depending on characteristics of the production facility (path and area) and the products moved (frequency), different handling equipment is suggested. Further research is done on the types of conveyors, where an appropriate choice depends on characteristics, such as (i) the product, (ii) the moving direction, (iii) the process control, (iv) bottom surface and (v) material weight.

Results

For every station, the current labour utilisation level and the required time per activity are determined. It turns out that Robot 1 has too much work, while the other workstations have a utilisation ratio of around 60%, which is quite low. Smaller improvements, such as buying extra pallet carts or replacing the cleaning tools from three poles to one swivel arm on top, help save some time and make the tasks easier for the handlers. Buying a semi-automatic strapping cart reduces the strapping time with 67%, equal to almost one hour per shift.

The reallocation of tasks is done by taking into account the restrictions and implementing the theoretical insights, resulting in three solutions:

1. Replacing tasks from AWA tables 17&20 to Robot 2 until only one handler is required at the AWA tables.
2. Moving all AWA table related tasks from Robot 2 to the handlers at AWA tables 17&20, where the handlers at tables 17&20 also perform the packaging tasks.
3. Moving all AWA table related tasks from Robot 2 to the handlers at AWA tables 17&20, where the Robot 2 handlers performs the packaging tasks.

It turns out that all three solution option are helpful in case a strapping machine is implemented. The amount of handling equipment depends on the reallocation of the tasks. Promens prefers a combination of solution option two and three, based on adaptability to changed workload, improved robot utilisation, costs, visualisation of workload and better monitoring of the quality. Table 1 shows the outcome of this combined solution.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA tables 17&20:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	Robot 1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
	Robot 2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
	Total:		**21:37:48**		**4**
Solution 2 & 3 combined:	AWA tables 17&20:	Trim, quality check, drill holes, bring to cooling, clean, assemble and flame from AWA tables 17,20 and R2 + stack & package all stations	13:21:40	172%	2
	R1:	Clamp, remove scrap, unclamp, clean and assemble	05:13:22	67%	1
	R2:	Clamp, remove scrap and unclamp	02:08:57	28%	0.5
	Total:		**20:44:00**		**3.5**

Table 1: The current situation and the final solution compared with each other. A different task division together with a strapping machine saves half an employee.

Recommendations

A combination of solution option two and three is only possible when buying a semi-automatic strapping machine and four conveyors. The investment costs are € 4270,-. The suggestion is to place two of the four conveyors at Robot 1, so the packaging workstation can easily see the amount of finished products. The other two are placed between the AWA tables and Robot 2 and between Robot 2 and the packaging station.

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Glossary of terms

AWA: stands for the Dutch word ´afwerkafdeling´, which can be translated to the finishing department.

One-piece flow / Just-In-Time: only the amount of products is produced that is demanded in the next stage of the process.

SHA: Systematic Handling Analysis, method to analyse and improve the production flow.

Machine: rotational moulding machine.

Robot: robot for activities related to drilling and milling.

Handler: an employee handling the product by moving or working on it.

Operator: the employee operating the rotational moulding machine.

Workstation: the place in the production hall where the handler or robot handler performs his or her tasks.

1 The introduction

This chapter introduces the company where the research takes place, whereafter it provides insight in the research design. The research design involves the research motivation, the identification of the core problem, the plan of approach and the research questions.

1.1 The company Promens

The company Berry Promens is founded in 1966 in Deventer. It produces plastic hollow products with the use of rotational moulding. In total, the company has around 80 employees. Approximately 20 employees are working in the office and the other 60 employees are performing their tasks in the three production halls the company has. Promens is highly focused on their relationship with their customers. Their vision entails number one safety for their employees, providing the opportunity to make the best out of themselves and a circular economy (Promens, 2020).

Production hall one contains five machines that produce the smaller products, such as garbage cans, water tanks for the caravan or RV, or components used in wind turbines. Figure 1.1 displays some of those products.

Figure 1.1: Multiple types of water tanks, which are some of the produced products in hall one.

The second hall produces their brand product, the Varibox. Their third hall has the biggest rotational moulding machine that produces big tanks that can be assembled on vehicles used in the agriculture or on the road. After those products come out of the machine, it requires actions such as trimming the seams, drilling holes in it, cleaning the products and packaging it to finish the product.

Other divisions at the company are ´Comex´, which stands for ´centraal onderdelen magazijn / expeditie' which in English is called the central parts warehouse / expedition. The section 'TD' stands for 'technische dienst', in English called the technical service department, with the grinding room and the mould storage.

1.2 The problem identification

The problem Promens faces is that they have the feeling that the workload among their employees is not equally divided. They notice that sometimes the employee at one workstation has time left, while the employee of another workstation needs to rush and cannot handle the amount of work. The company does not know how much time a certain handling takes and therefore they are not able to make decisions to make better use of their employees. A consequence of this problem is that the employee costs are higher than needed, which is not desirable. Collecting new data from the current situation is required to make decisions on.

The research involves the employees performing the actions, their team leaders and the production management, present in hall one. For the scope of this research, the rotational moulding machines with its employees will be involved.

Promens also faces some other problems influencing their product costs. The amount of used material influences the material costs. The employees or the robots operated by the employees are cutting away excessive material, causing plastic shreds. they need to be clean, before these shreds are possible to collect and reuse. Therefore, improvements are possible to increase the amount of collected scrap material and thereby decrease the material costs.

Next, the production costs are of interest. Possible improvements relate to the production of the non-approved products and the labour utilisation of their employees. The cause of the low utilisation rate, is because the employees are all working at their own production line. Each production line has different types of products on the machine, which leads to an unequal workload. The problem is that when making the production schedule, they do not take into account the differences in workload for the handlers. Because of the lack of data, Promens cannot make decisions on how to improve their labour utilisation among their employees, which is the core problem of this research. The difference between norm and reality is the lack of data present to underpin proposed solutions. The reality is the current labour utilisation at every workstation and the norm is to save get this labour utilisation more equal and maybe save an employee. Figure 1.2 visualises the link between the established problems.

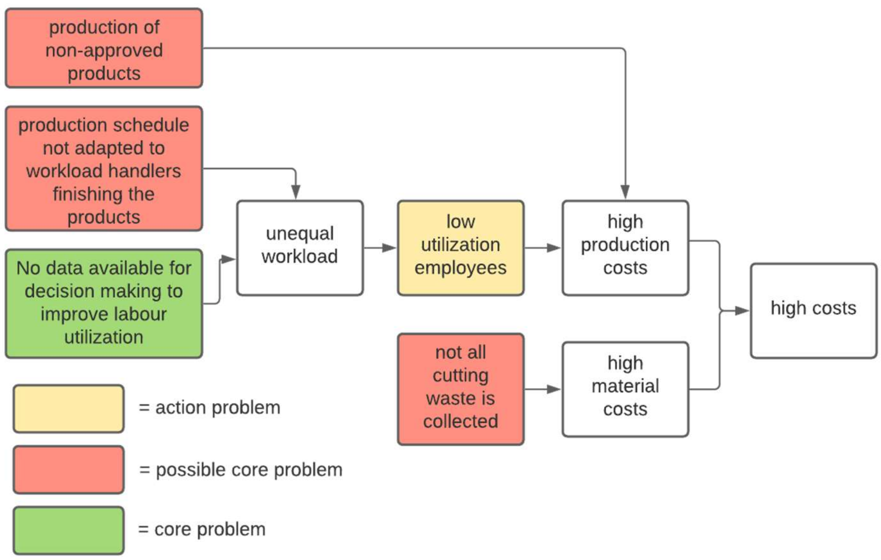

Figure 1.2: The problem cluster with problems involving the high product costs. The chosen core problem is the lack of data required for making decisions on.

1.3 The research design

The Managerial Problem-Solving Method (MPSM) together with the Do, Discover, Decide (D3) form the base of the research set up. Appendix D and E summarize the different steps of these methods. Section 1.4 describes the first two steps of the MPSM, defining and formulating the problem.

Step three involves analysing the problem with the help of the SHA. Developing a flowchart for every workstation identifies the activities that take place, which forms the base for determining together with the company board, what activities to be measured. Quantitative data is collected by measuring the time the activities take. Doing semi-structured interviews provides a qualitative analysis over the gathered data. With regards to Discover, investigation of these activities is required to get a full understanding of the current situation. The product flow diagram visualises the movements of the products inside hall one. This step provides answers to the following questions:

1 *What is the current production process at Promens?*
- What are the different activities performed by the employees and in what order?
- Which products are appropriate for performing the measurements on?

2 *What is the current performance of the production process?*
- What KPI's are currently in place?
- What is the current labour utilisation?

Chapter three provides answers to the first question and chapter four to the second question.

Step four entails formulating possible solutions to increase the labour utilisation. The flowchart and gathered data form the base for the analysis on where time is lost. The gathered theory focusses on decreasing the walking distances of the handlers and finding the right handling equipment. Next to performing a literature study, the requirements and restrictions are formulated by performing an observation study and having semi-structured interviews. The combination of gathered theory, the limitations and the required time per activity results in several solutions. The questions this step provides an answer to are:

3 *What knowledge in the literature is available regarding increasing the utilisation of employees at a production process?*
- What methods are accessible to decrease the walking distances in a production process?
- How can the handling of the products being improved using the Systematic Handling Analysis method?

4 *What are the restrictions and requirements for the production process of Promens?*
- What does the production hall has to comply with to be a safe and ergonomic work environment?
- What does the production hall has to comply with to remain sustainable?

Chapter 5 answers research question three. Section 6.1 and 6.2 implements the theory into the production process of Promens and provides a list of the restrictions and requirements, thereby answering question four.

Step five is choosing a solution from the list, thereby focussing on the 'Decide' part of the D3. Reallocating the tasks forms the new solutions. The earlier collected measurement of the required time per activity will function as validation. The choice requires a calculation of the costs for every solution. Next, with defined criteria, the board will rate and analyse every solution and provide their insights and preferences. Section 6.4 shows the results of the different solutions. Section 6.5 shows the rating from the company board, their preferences and the final solution. Section 6.6 provides a guideline on how to implement the chosen solution.

5 *Which improvements are possible to be implemented in the production process?*

- What alternatives are promising?
- What are their pros and cons?
- What choice is recommended?

6 *How can Promens implement and monitor the results of the solution?*

Table 1-1 gives the overview of the plan of approach, the activities and the number of the questions that are answered in the several chapters.

Table 1-1: The stepwise approach for every sub question connected to the belonging chapter.

MPSM:	Activity:	Do:	Discover:	Decide:	Chapter / section:	Subquestion:
Step 3: analysis	Product choice	Analyse the products (SHA)	Type of products	Level of detail from the products	3.2	1
	Flowchart	Observation	Different activities		3.3	1
		Presenting to company supervisor		Scope, level of detail	3.3	1
	Gathering data	List the measured activities		Decide what activities with company and flowchart	3.3	1
		Quantitative, time measurements	Time per activity		4.2	2
		Qualitative, semi-structured interviews	Reasoning the time per activity		4.2	2
Step 4: formulate solutions	Theory gathering	Determine keywords (theoretical framework)	Knowledge available	What knowledge to use	5	3
	List requirements and restrictions	Analysis per workstation	Mandatory actions and equipment		6.2	4
		Semi-structured interviews	Check list requirements and restrictions		6.2	4
	Think of solutions	Theory implemented in production process		Limitations involvement	6.3	5
	Validation solutions	Use collected data, make e.g. simulation, simplified model, statistical analysis, etc.	If improvement increases labour utilization	Whether iprovement is the right choice	6.3	5
Step 5: choose solution	Cost estimation	List required equipment			6.4	5
		Unstructured interviews	Negative / positive influences of improvement	If improvement is worth the implementation	6.4	5
	Choose improvement point	Define criteria	Based on: limitations defined, negative consequences and core problem.		6.5	5
		Appointment with production manager	Opinion production manager	What improvement to develop, based on criteria	6.5	5
Step 6: implementation	Implementation plan	Define order of improvement			6.6	6

2 The theoretical framework

This theoretical framework functions as a guide to understand the production process of the company Promens by first introducing the manufacturing process of rotational moulding. Next to that, Promens strives for the lean principle, elaboration is given in section 2.2. The Systematic Handling Analysis is a tool to guide the process of mapping a production process and its belonging movements.

2.1 Rotational moulding

Rotational moulding is a manufacturing process that gives the possibility to produce plastic hollow products, mainly for products having different geometries and smaller batches. The first step is to fill the mould with the desired colour plastic grains. Then, the mould will close and it gets heated up while the mould is spinning to all possible sides. The heating will make the plastic grains that are inside melt and those will stick to the surface inside the mould. The manufacturer has the possibility to choose what sides of the mould will have a plastic on it by editing the surfaces on places where he does not prefer plastic to stick. Some of the moulds have screw thread in it, allowing the product to screw a lid on it once it gets out of the machine. After the product gets into shape, the mould first needs to cool down before it can be opened. During the cooling, the mould needs to turn to all sides as well. Once the product and the mould are cooled down, it is taken out of the machine. The product can still be around 85 degrees (Lutters, 2020). Figure 2.1 displays the four steps (Roto Industry, 2014).

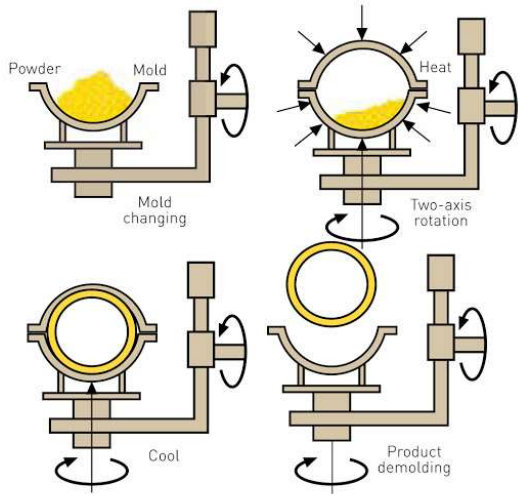

Figure 2.1: The four steps of rotational moulding. After adding the powder, the mould closes and gets heated up. During the heating and cooling the mould turns to al sides. The last stap is to remove the product.

The machine itself has three places, a loading and unloading bay, an oven and a cooling room. Step one and four, filling and emptying the moulds, is performed at the loading and unloading bay. Step two of the process takes place in the oven and step three, the cooling, takes place in the cooling room. Because of these three stations, the machine has at least three arms rotating through those different stations. Before the arm goes in the oven or cooling room, a door opens and the arm can go in. The cycle time of the machines depends on the type of material, the type of products, the thickness of the walls and other characteristics (Promens, 2021). Figure 2.2 displayes the three stations of the machine (OpenLearn, 2017).

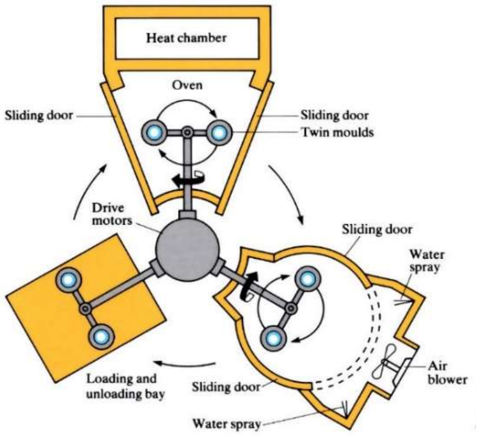

Figure 2.2: The rotational moulding machine with the three stations, loading and unloading bay, the heating room and the cooling room.

The material of the products is thermoplastic plastic, meaning that when the material is molten, it has the possibility to reshape. Thermosetting plastic is not an option, because once that material is in the correct shape, it cannot be reshaped. Products made by rotational moulding are recognizable by not having an injection pin and being hollow. The thickness of the walls differ a bit and the inside and outside of the product have a smoother surface. In case the surface is not smooth, it might be rejected. Next to that, there is a line around the whole product at the height of where the two parts of the mould meet. This line is not desirable and is therefore removed in the finishing process of the product (Lutters, 2020).

2.2 The lean principle

The lean principle focuses on defining value from the customers viewpoint. More specific, the goal is to improve the production process by eliminating waste that does not contribute to that customer value. The origin of lean lies at the Toyota car manufacturing plant in Japan in the 20th century. The difference back then between Ford and Toyota is that Ford was using a flow production system focussed on mass production, whereas Toyotas customers demanded more variety between the cars and thereby requiring a more flexible method of producing(The Lean Way, n.d.). Toyota introduced two concepts, “Jidoka” and “Just-In-Time”. The concept of Jidoka is that the production stops when a problem occurs, to prevent defect products from being produced. Just-In-Time is the concept that only the amount of products is produced that is required in the next stage of the process. This results in having less stock in between the stages and creating a more continuous flow (Slack et al., 2013).

Figure 2.3 shows the five step approach for implementing the lean principle. The first step is to determine the characteristics with value for the customer. The next step is to map and examine these on their value. Third, a flow throughout the process is created by removing waste, so the steps are closer to each other. A shorter flow gives the opportunity to use the pull technique. The last step is to determine the optimal balance for the new situation, whereafter the whole process starts over. This results in continuous improvements over time of the production process (Lean Enterprise Institute, n.d.).

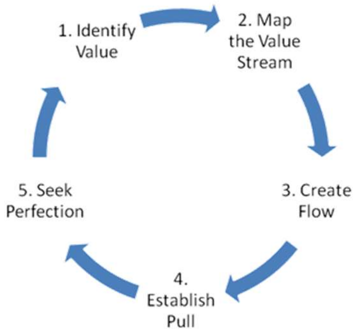

Figure 2.3: The five step approach for implementation of the lean principle.

The Pull technique is one of the main concepts within lean manufacturing. Only when the next stage in line asks for a product, the stage itself will produce the product. Therefore, The pull strategy only starts when a customer asks for a product. This demand passes upfront until the first stage, whereafter the product goes through the different stages in a continuous flow, resulting in synchronization between the different stages. The stages need to cooperate with each other and motivation arises to solve problems that as one whole chain, instead of redirecting that problem only to one stage. The pull strategy lowers the in-between buffers, making it easier to identify possible productivity problems. Causes of waste are Muda, being not value adding, Mura, having no consistency, and Muri, having unreasonable requirements. Waste is divided into four categories: waste from having an irregular flow, waste from inexact supply, waste from inflexible responses and waste from high variability (Slack et al., 2013). One piece flow theory comes together with the lean principle. It focusses on not having stocks in-between the different departments and thereby reducing the lead time of the products. Thereby, it has the same goal as the Just-In-Time concept combined with the pull technique. The lean methods require flexibility of the employees, so they can perform multiple tasks at multiple stations (Sekine, 1992).

2.3 The Systematic Handling Analysis

The systematic handling analysis is a widely used method to analyse the different handlings that take place in a factory. The method introduces a clear step wise approach for gathering the required information as well as analysing that information. Figure 2.4 shows the different steps of the SHA.

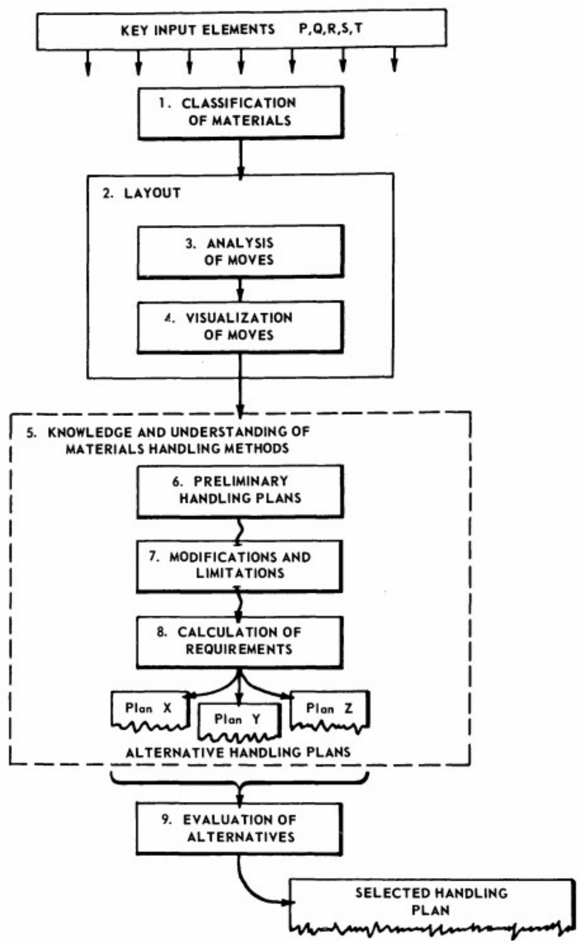

Figure 2.4: The stepwise approach of the Systematic Handling Analysis.

The execution of the steps provides the following key inputs, where P stands for product, Q stands for quantity, R stands for routing, S for supporting services and T for time. The first step of the SHA classifies the materials based on their physical and other characteristics. SHA provides multiple sheets based on their research that can be used throughout the process. Step two, three and four focus on the layout. There are three types of layout, called the layout by fixed position, layout by process and the layout by product. The choice of layout depends on the product and the handling options. Table 2-1 displays the differences between the layouts (Muther, 1969).

Table 2-1: The recommendation for the type of layout depends on the characteristics of the product and the preferred handling method.

	product			Handling:
	type:	quantity:	process difficulty:	
layout by fixed position	large	small	simple	sturdy
layout by process / function	diversified	moderate / small	expensive	flexible / versatile
layout by product	standardized	high	simple	continuous

Within these layout types, possible flow patterns are a straight line process, an L-shape process, a U-shape process or a combination between the three.

Step three involves an analysis of the moves made. This takes into account three aspects: the material that will be moved, the route it will take and the flow itself, where the material is defined in the first step. The route involves the distance the product has to travel and the physical situation of that route. For the physical situation, characteristics such as straightness, congestion, surface, climate and the terminal situation are of interest. Taking into account the intensity of flow and the condition of the flow determines the type of flow. The intensity of the flow involves the frequency and amount of material that is moved within a period of time. The condition of the flow involves quantity conditions, service conditions and timing conditions and thereby give answer to the required values of Q, S and T. Figure 2.5 shows the sections from the different letters.

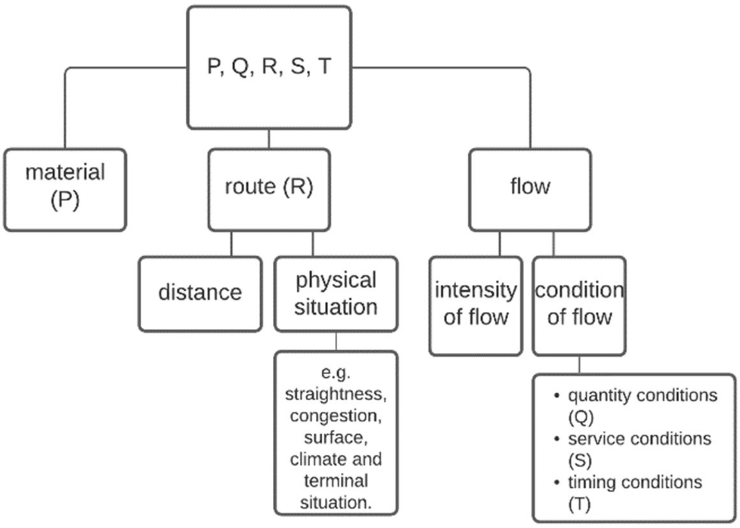

Figure 2.5: A visualisation of the sections the characters belong to.

Table 2-2 shows the symbols used for the different types of activities.

Table 2-2: The type of activity with their belonging symbols.

○	Operation
⇨	Transportation
	Handling
▽	Storage
□	Inspection

Step four concerns about visualizing the determined flow in the factory with the use of a flowchart or a distance-intensity plot. The best option is a combination of the two. However, in case of a relatively simple problem, a flowchart complies.

From step five onwards, the SHA introduces several handling options to form an alternative handling plan. Step six involves proposing new methods for moving the products along the process. Whereafter step seven focusses on the possible modifications and limitations. Lastly, step eight focusses on determining the possible costs of the newly formed handling plans. The evaluation of the different solutions is step nine, in which the final choice will be made. The last steps are highly dependent on the type of production process, the determined variables and the solutions that are possible.

Section 3.2 involves the execution of step one. Section 3.3 and 3.4 explain step two, three and four. Step five, understanding the types of handling equipment, is the literature study executed in chapter five. Step six, seven and eight, involve the development of several options. Chapter six elaborates on it.

3 The current production process

This chapter introduces the current situation of the different activities practised at production hall one. First, the production hall itself is displayed, whereafter the types of products and the performed activities are determined. Next to that, the flow through the hall are listed and characteristics of the process are presented.

3.1 The layout of hall 1

Appendix A provides the layout of the whole factory. Figure 3.1 shows the setup of the workstation in hall one, where the research takes place.

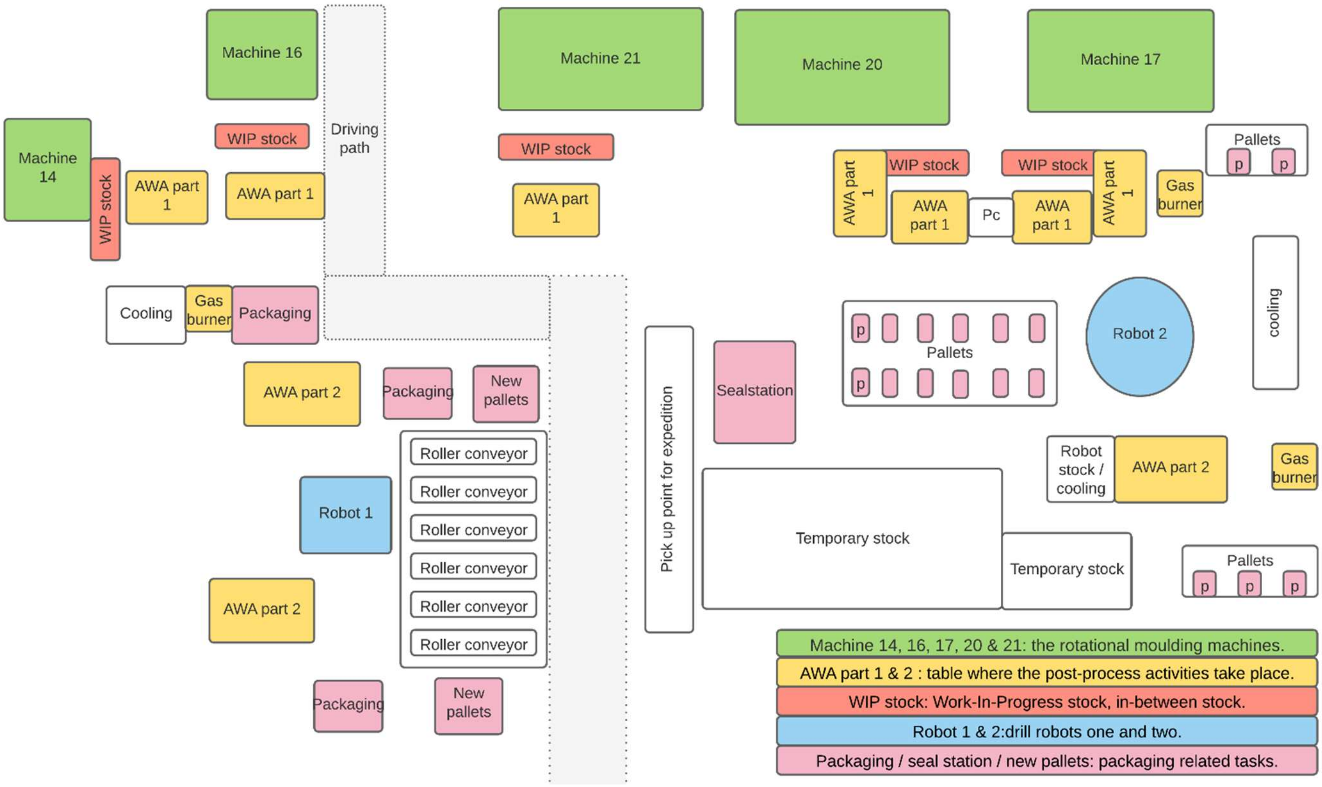

Figure 3.1: The floor plan of production hall one, with five machines, two robots, and four AWA handling tables.

3.2 The types of products (SHA 1)

Classifying the products simplifies the production facility and thereby helps to solve the handling problem (Muther, 1969). The first step of the SHA for identifying the different products is determining the product characteristics and its quantities. Lots of products produced by Promens have almost similar characteristics, which have less to no influence on the handling process. Therefore, the qualification for the products is done on a higher level than the product codes and they are selected in resembling item groups. Table 3-1 shows the four groups.

Table 3-1: The type of products grouped, depending on their characteristics and intensity of production.

material characteristics V = 'or'

plant: Promens Deventer BV	Project: Thesis assignment
By: Ilse Grootte Bromhaar	and:
Date: 20/4/2021 - 12/5/2021	Sheet number: 1

product-material description	smallest practical unit of item	physical characteristics of unit: length [m]	width [m]	height [m]	weight per unit [kg]	shape	risk of damage	condition	other characteristics: quantity	timing	special control
small (regular)	one piece	< 0,5	< 0,5	< 0,5	< 8 kg	square / irregular	slight fragile	warm (max 60° C)	48%	regular	-
big (regular)	one piece	> 0,5	> 0,5	> 0,5	8 kg > X < 16 kg	square / irregular	slight fragile	warm (max 60° C)	42%	regular	-
small (seasonal)	one piece	< 0,5	< 0,5	< 0,5	< 8 kg	square / irregular	slight fragile	warm (max 60° C)	5%	seasonal	-
big (seasonal)	one piece	> 0,5	> 0,5	> 0,5	8 kg > X < 16 kg	square / irregular	slight fragile	warm (max 60° C)	5%	seasonal	-

The use of the excel file 'dbo_tbl_ActualProduction',provided by Promens, determines the percentages of the intensity for each product group. The heaviest products weight around 16 kg. The weight of the products is the norm for the different product groups, where lighter than 8 kg is seen as a small product. In the last few years, Promens made the choice to have less variation in their production process, so only the last three months are taken into account.

The next step is to perform a product-quantity analysis. The seasonal percentages are an estimation. The regular percentages are calculated over the last half year using the provided database and by selection on the weights. The combination results in the line in Figure 3.2. The more straight the line is, the less classes are required (Muther, 1969). Because it is not very curved, the conclusion is that the research does not require much classes to resemble the different product groups.

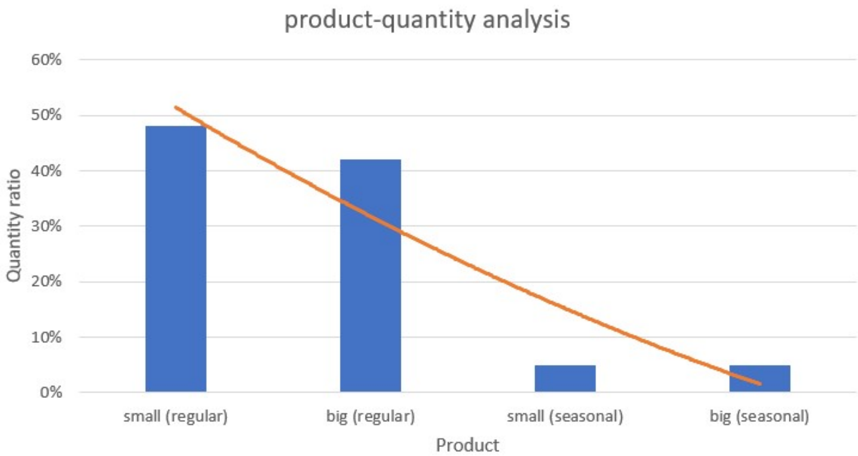

Figure 3.2: the product-quantity analysis. The steeper the line, the less product classes are required.

Table 3-2 gives the summary of the classified materials. Because of the pre-selection in table 3-1, only the assembly parts and the packaging parts are added to the list.

Table 3-2: The different material classes, having two product groups, the assembly parts and the packaging materials.

plant: Promens Deventer BV	Project: Thesis assignment
By: Ilse Grootte Bromhaar	and:
Date: 20/4/2021 - 12/5/2021	Sheet number: 1

Material class		classification criteria		examples
description	class identif.	physical characteristics	other characteristics	
small	a	lighter than 8 kg, easy to lift by hand	high production rate, some are seasonal.	EV2424
big	b	heavier than 8 kg, bit harder to lift by hand, but still possible	high production rate, some are seasonal.	X13005
assembly parts	c	Light and small. Delivered in boxes.	easy to attach, required at almost every product, brought once or twice per shift.	lid and rubber ring, or sticker.
other	d	pallets, bit heavy. carton boxes, light.	high usage rate.	euro pallet, palletsize box

Overall, Promens produces products with characteristics that do not influence the production process much and therefore it is one-material production problem (Muther, 1969).

3.3 The performed activities

The different activities present in hall one are possible to group into four departments: the rotational moulding machine, the AWA table, the robot and the packaging. For each department, a more extensive flowchart is presented. The flowcharts are based on the route of the product and not on the order in which the handlers work. Differences are elaborated on in section 3.3.2.

3.3.1 The production Processes (SHA 3)

The overview

Figure 3.3 shows an overview of the four departments. The shapes in the flowcharts follow the basic principles (Gilbreth, 1921). The round blue circles indicate the start and end of the process, the squares represent an activity and the triangles represent an decision point. An employee will fill the machine and once the product is cooled down, the handler from the AWA table will process the product further. Sometimes, the product is placed in the robot that makes holes. Otherwise, the AWA handler will make the holes by hand. Then, the second part of the AWA handlings takes place. Once the product is finished, it is placed on one of the pallets. Once the pallet is full it is packaged, which is the final stage. Figure 3.4 shows the setup of the AWA handling tables 17&20 and Robot 2.

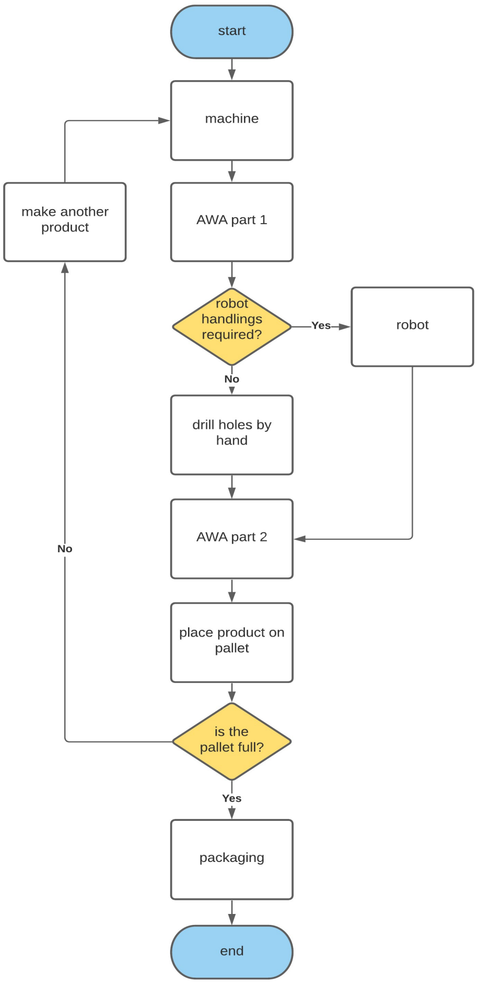

Figure 3.3: The process overview.

Figure 3.4: AWA 17, 20 and Robot 2 with cars in front where the products cool down.

The rotational moulding machines

Figure 3.5 shows a flowchart concerning the activities at the rotational moulding machine. After the mould is opened, the product coming from the cooling room is removed and the mould is cleaned, before powder is added coming from a bag or from the powder transport. After closing the mould, a check is done if the other moulds are also filled and the machine is turned on. Some of the products that come out of the machine need to be pressurised in clamps for securing the right shape while further cooling down. Figure 3.6 and 3.7 shows the rotational moulding machine from two perspectives.

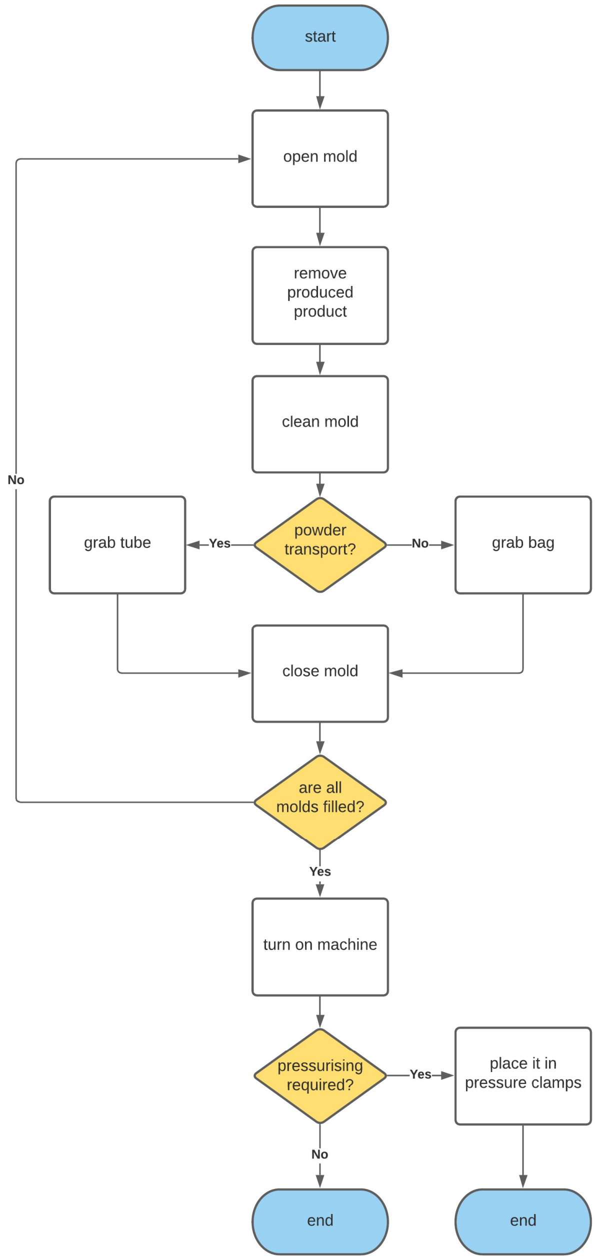

Figure 3.5: The moulding machine process.

Figure 3.6: The rotational moulding machine, two of the three arms are visible.

Figure 3.7: The rotational moulding machine with open mould and powder inside.

The AWA handlings

After the products leave the machine, the AWA table will process the product Figure 3.8 shows the first part of the steps. The product is picked from the cooling or WIP stock and the edges are trimmed. Because the products are mainly for fluids, it is checked on possible leakages with the air pressure measurement equipment, shown by Figure 3.9. Depending on the product, holes are drilled by the handler or by the robot, whereafter Figure 3.10 shows part two of the execution of the AWA steps. Because of the trimming and drilling, plastic scrap ends up in the hollow product and therefore these are vacuum cleaned. Sometimes, the customers prefer to have the product assembled with lids, stickers or other components. Other requirements for the customer might be the finishing touch of the surface. By flaming the product, the surface will be smoother and a bit shiny. Figure 3.11 shows the overview of the set up at the AWA tables 17&20.

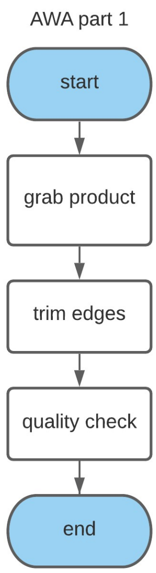

Figure 3.8: The first AWA handlings before drilling.

Figure 3.9: The equipment used by AWA, from left to right: air pressure machine, a knife, a safety knife, a lid-screw tool and a drill.

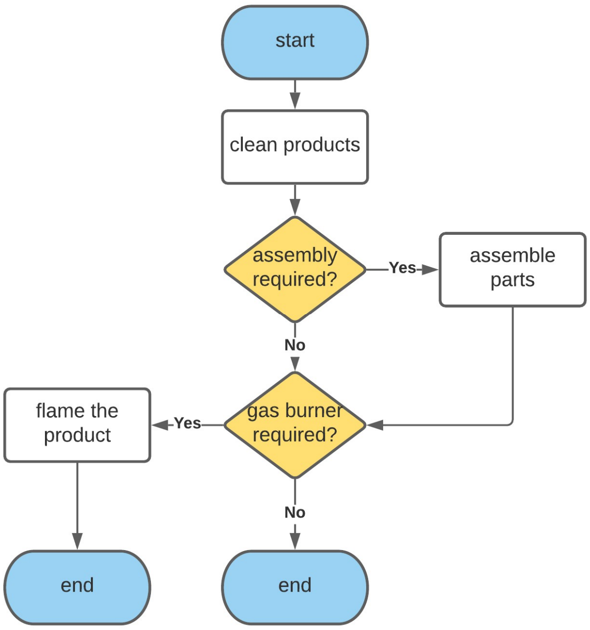

Figure 3.10: The second AWA handlings after drilling.

Figure 3.11: The work tables AWA 17 and 20, with the computer and garbage bin in the middle.

The robot handlings

Some of the products pass the robot, which depends on several factors. Before the product can pass the robot, a robot program is required. This is done at the robot itself, so the robot stands still and cannot continue with other products in the meantime. Therefore, the consideration is taken if the products and the advantages are big enough to have the robot standing still. Next to that, some products are too difficult to be taken care of by the handlers themselves, while the robot is able to do that precision work. Lastly, the robot drills the holes much faster, so the lead time is lower and the handlers have more time for their other tasks. Figure 3.12 displays the steps done at the robots. First, a product is picked from the cooling cart and placed in the special made jiggs. When the door of the robot is closed, it can start drilling. Once the robot is finished, the handler will remove the scrap pieces and unclamp the product. Figure 3.13 shows Robot 1. Figure 3.14 shows the setup of Robot 2.

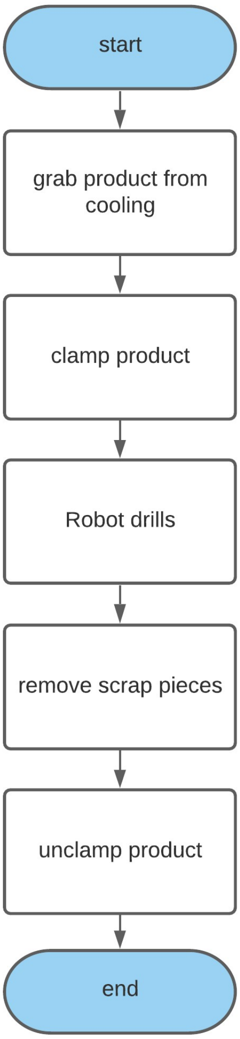

Figure 3.12: The robot handling process.

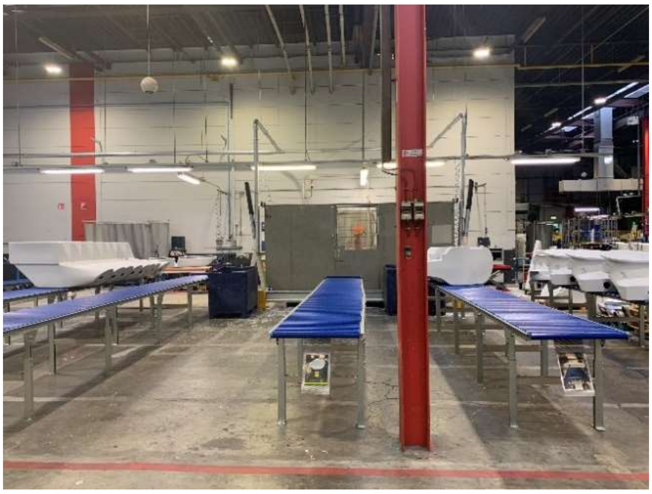

Figure 3.13: Robot 1 with two work cells and roller conveyors in front.

Figure 3.14: Robot 2 with six cells and a pole with cleaning tools in the front.

The packaging handlings

Figure 3.15 shows the packaging process, which is the last stadium for the products before they go to expedition. Once a pallet is full, it is sealed at the seal station. First, a pallet cart is grabbed from somewhere in hall one. To prevent the products from falling, they are sealed by hand or strapped at the same spot as where they are stacked. Sometimes, when the pallets arrive at the seal station, a plastic bag is placed over it before the sealing starts. Once the seal station is finished, the pallet with the products is moved to expedition and a new pallet is brought to the stacking spot. Depending on how the products are packed, a carton box needs to be unfold. Figure 3.16 shows the seal station.

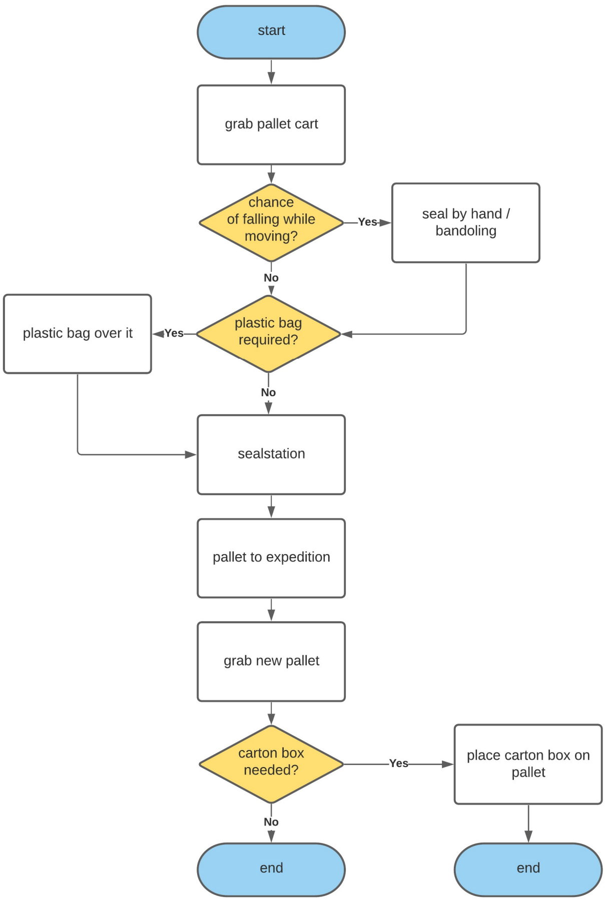

Figure 3.15: The packaging process.

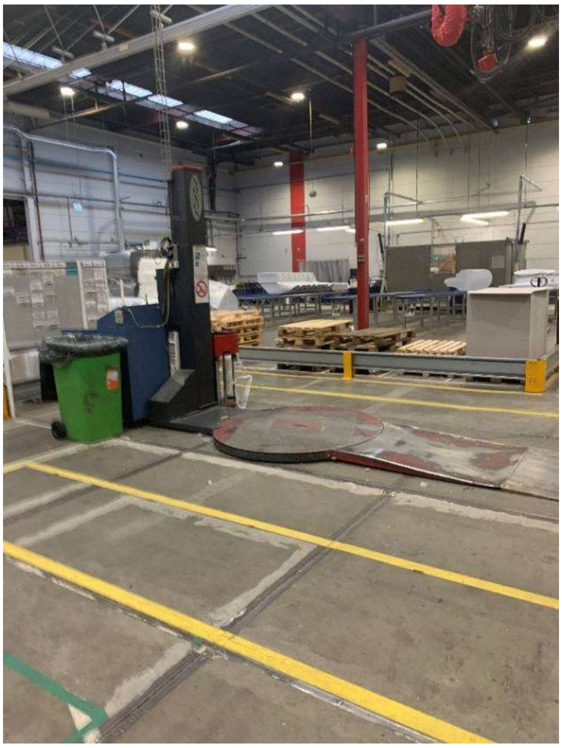

Figure 3.16: The seal station. The plate in the middle turns around and the pallet gets sealed.

The analysis of moves

Table 3-3 shows a process chart, step three of the SHA. This is an overview of the status of the products at a type of activity, with the characteristics such as the weight, the intensity and the distance the products travels.

Table 3-3: The process chart, mentioning all steps taken with the production process. Some of the products pass the robots, others are completely handled by the AWA tables. The activity numbers correspond in Figure 3.17.

Process chart

Plant: Promens Deventer BV	Project: Thesis assignment
By: Ilse Grootte Bromhaar	
Date: 20/4/2021 - 12/5/2021	Sheet number: 1

○	Operation
⇨	Transportation
⬠	Handling
▽	Storage
□	Inspection

Conversions for charted unit to end unit:				
Charted unit:	Size / weight:	Quantity per end unit:	Start point:	AWA tables 17&20
Unassembled product:	4-16 kg	1	End point:	Expedition pick up point
Assembled product:	4-16 kg	1		
Pallet with products:	± 90 kg	4-30		
Empty pallet:	± 20 kg	1		
Carton box:	< 1 kg	1		

Charted process: Finishing hollow products that come out of the machine

The activity number:	Charted unit and units per load:	Activity symbol:	Description of action:	Weight / size of load: [kg]	Number of trips per day:	Distance: [m]	Notes:
1	Unassembled hollow product, 1	▽	Next to other products on table	-	-	-	-
2	Unassembled hollow product, 1	○	Trim edges	± 10	379	-	
3	Unassembled hollow product, 1	□	Quality check	± 10	379	-	
	AWA or ROBOT:						
	AWA						
4	Unassembled hollow product, 1	▽	Cooling	± 10	142	1	
5	Unassembled hollow product, 1	○	Drill holes	± 10	142	-	
	ROBOT						
6	Unassembled hollow product, 1	⇨	Bring to cooling	± 10	237	18	
7	Unassembled hollow product, 1	▽	Cooling	± 10	237	12	
8	Unassembled hollow product, 1	⬠	Clamp product	± 10	237	5	
9	Unassembled hollow product, 1	○	Robot drills	± 10	-	-	
10	Unassembled hollow product, 1	⬠	Remove scrap pieces	± 10	237	2	
11	Unassembled hollow product, 1	⬠	Unclamp product	± 10	-	-	
12	Unassembled hollow product, 1	⇨	Go to table AWA Robot	± 10	237	12	
13	Unassembled hollow product, 1	⬠	Clean product	± 10	379	-	
14	Unassembled hollow product, 1	○	Assemble parts	± 10	379	1	
15	Assembled product, 1	○	Flame product	± 10	113.7	10	
16	Assembled product, 1	⇨	Bring product to pallet	± 10	379	12	
17	Pallet, 1	⬠	bandoling / plastic bag	± 90 kg	49	-	
18	Pallet, 1	⇨	Go to sealstation	± 90 kg	49	15-20	Pallet cart required
19	Pallet, 1	⬠	Seal the pallet	± 90 kg	49	-	
20	Pallet, 1	⇨	Pallet to expedition pick up point	± 90 kg	49	15	
21	Empty pallet, 1	⬠	Grap new pallet	± 20 kg	49	25-35	
22	Carton box, 1	⬠	Grap carton box	< 1 kg	13	15	
	3 x ▽ 5 x ○	5 x ⇨	8 x ⬠ 1 x □		**Total distance:**	**143-158**	**meters**

3.4 The production flow (SHA 2 and 4)

Step four is the visualisation of the process chart. Section 2.3 elaborates on three types of layout, the layout by fixed position, the layout by process / function and the layout by product. The production process at Promens is not really difficult and the process is based on the lean principle with one-piece flow. The best layout option for Promens is the layout by product, because the type of product is quite standardized, has a relatively short production time and is therefore a high quantity product.

Shows the production flow of the products and pallets through the production hall. As suggested by the SHA, the numbers represent the activities in the process chart. The chapes at the departments represent the activity type.

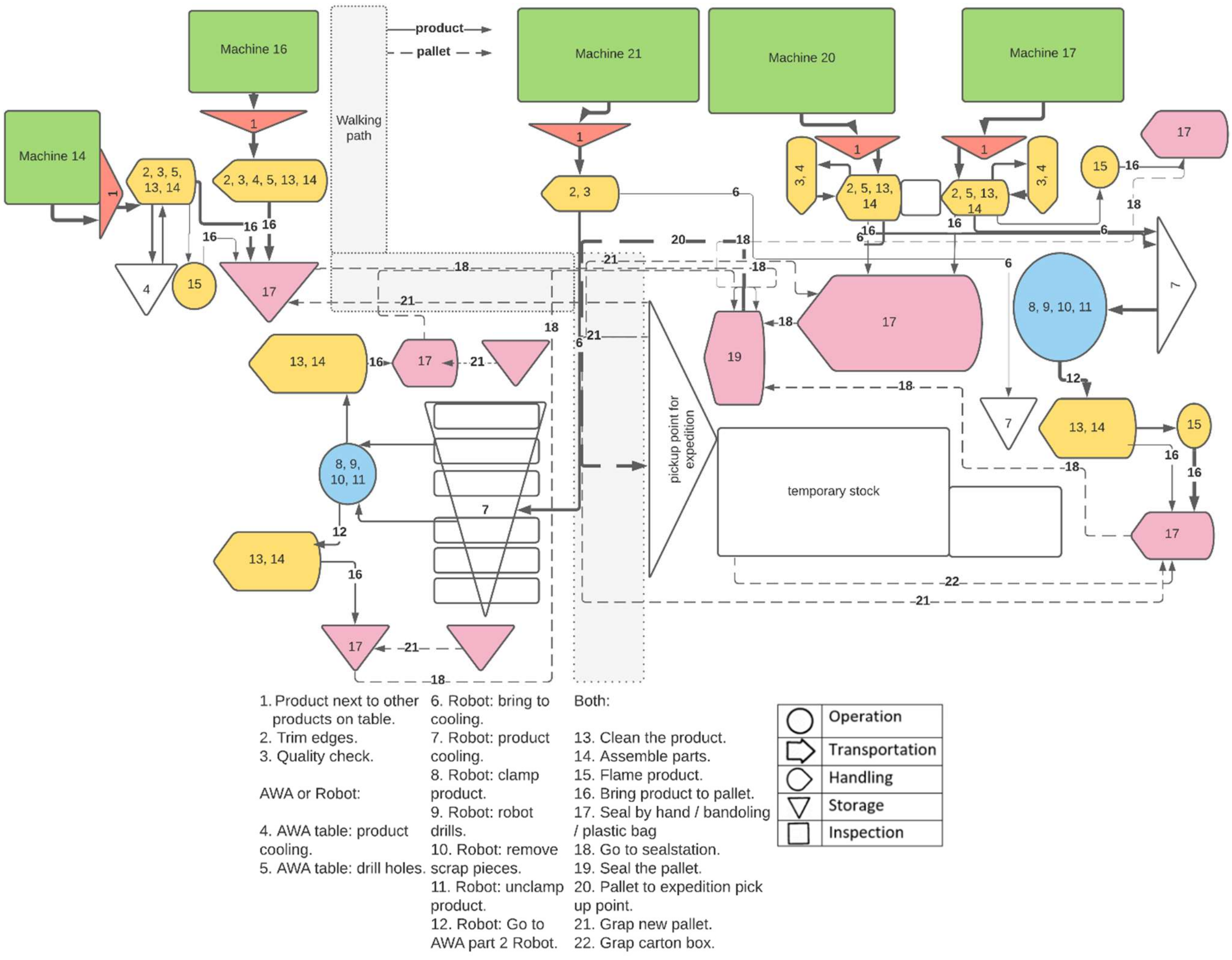

Figure 3.17: The product flow in hall one, a thicker line indicates a higher flow intensity, the numbers and shapes correspond with the information in the legend. Some of the products pass one of the robots, other products are completely finished by the AWA tables.

3.4.1 The handlers

The handlers perform tasks at multiple workstations, because they all package their own products. Robot 1 is most of the time very busy, so handlers from AWA table 17&20 or Robot 2 will help out and sometimes perform the packaging task for him. Another difference between the product flow and the work sequence of the handlers handlers, is that when the product comes out of one of the robots, part two of the AWA tasks is done by the person standing at Robot 2. The handlers at the robots do the same AWA tables part two tasks as being performed at AWA tables 17&20.

The company works with two shifts, a morning shift from 5:45 till 14:30 and an afternoon shift from 14:30 till 23:00. The employees always work in the same shift, meaning they always work with the same colleagues. Every week, the morning and afternoon shift switch around and they work the other shift than they did the previous week. Their total time for a break is 45 minutes per shift. During their work, they are allowed to have a coffee or toilet break and therefore the company does not give them work for a full hour each hour.

Keeping the rotational moulding machine flowchart out of scope, most of the activities performed by the handlers is stated in the flowcharts. Next to the activities required for finishing the product, other activities are performed. Every workstation has a computer where they can check what is expected from them during their shift and they can register their finished products. At the end of their shift, the work stations are cleaned and sometimes work transfer information is given to the next shift.

Activities they do not have to perform are bringing the pallet from the production hall all the way to the expedition hall. This is done by fork lift drivers from the expedition department. The COMEX department sorts and brings the assembly parts, empty pallets and other packaging equipment. Some products are repaired after they come out of the machine. This takes half a day and done in hall one, but not by one of the employees performing the regular tasks. Switching the moulds on the rotational moulding machine is done by the mechanical department. However, switching the jiggs at the robots is done by the handlers themselves.

3.4.2 Production schedule

The busyness of the employees depends on the products coming out of the machine. Some products take more time to process than others. A proper balance between the workload of the handlers at AWA 17 and AWA 20 is sometimes hard to find. This is due to the fact that the moulds have different sizes and therefore limit the options on which machine assembly is possible. Next to that, the production schedule is mainly focused on customer demands, so the production environment has to coop with the differences in workload over the period of time.

3.5 Chapter conclusion

Section 3.1 displays the layout of the five machines and the workstations in hall one. The SHA divides products depending on characteristics such as the size, shape, risk of damage, condition and quantity, resulting in four groups of products, big, small, seasonal or regular. The SHA states that less types of products require less difficult handling methods. For every workstation, rotational moulding machine, The AWA tables, the robots and the packaging, all steps are listed and visualised with a flow chart. The combination of the flow chart of the handlings and the process chart of the products results in an overview of flow in Figure 3.17. The handlers and production schedule are taken into account when performing the measurements from chapter 4.

4 The utilisation rates

Being able to present possible solutions requires existing and new data of the current situation of the production process in hall one. Section 4.1 provides an analysis of the existing data and clarifies how, why and when the newly formed data is collected to make it valid. Section 4.2 first analyses this data, whereafter a combination of both types of data, such as the dashboard and the measured required time per activity, provides the answer to what the current performance in the production process is at the several stations. The last section describes options for smaller improvements to decrease the handling effort of the employees.

4.1 The data gathering methods

The existing data consists production data over the last twelve years, the production plan of the measured weeks and a KPI dashboard from the production department. The new data focusses on the required time per activity at the different workstation. Section 4.1.2 explains the reasoning on how, why and when the measurements are taken, to ensure the validity of these measurements.

4.1.1 The existing data

Promens has a file containing data over the last twelve years of all orders that are processed. The file contains information regarding the production date and time, the stations that handle it, the handler itself, which shift it handles, if the product is produced correctly, the quantity within the order, the product ID, the weight, the estimated required handling time and other aspects regarding the order. When qualifying the several types of products, it requires the weight. The newly gathered data is more specific for calculating the required handling times, because Promens does not trust the estimated handling time stated in the file. Other files contain information about the production schedule at the machines during the measurements. These files contain partly the same data as the production order file, but provides extra information regarding the quantity of products produced. At the end of each week, the production results of the past week are known and displayed on a KPI dashboard. This dashboard contains information such as the rejection rate, the reparation rate, the emptiness rate and the realisation rate.

4.1.2 The measurements

Getting a correct view on the current situation requires extra measurements. By filling in the self-developed sheets based on the flowcharts in chapter three, the goal is to get an overview of how much time the different activities the handlers perform, takes. Appendix B shows these measurement sheets. There are three types of sheets, one for the AWA handling tables, one for the robots and one for the packaging.

The AWA handlings they can perform include: trimming the edges, doing a quality check, drilling holes, cleaning the product, assemble parts, and bringing the product to the robot or the pallet. The handlings belonging to the robot are: clamping the product, letting the robot drill, remove the scrap pieces and unclamp the product. The packaging involves the following handlings: grabbing a pallet cart, strapping or sealing by hand or both, sometimes adding a plastic bag, sealing at the seal station, bringing the pallet to expedition, grabbing a new pallet and depending on the product folding a carton box. Some of the AWA handlings are performed after the product passes the robot. Next to that, they perform the packaging activities themselves. Therefore, it requires all three types of sheets when following a handler. Next to that, measuring an extra activity not involving the finishing of the product is cleaning, which is done at the end of the shift.

For having a higher validity on the measurements, performing them is on timeslots when no employee is ill and all the machines are running. There must be no Work-In-Progress stock present that needs to be taken care of as well, e.g. due to illness or machine failure. Performing the measurements multiple times will give a better overview of the average, especially when keeping in mind to measure different shifts and thereby different handlers. During the measurements, there is time for extra observations to see whether their working area or production process can be improved. Section 4.3 elaborates further on this.

4.2 The data analysis

Analysing and combining the gathered data will result in a clear overview of the current situation, such as the results at the dashboard and the current labour utilisation. Formulating the several solutions requires the average time per activity at each workstation. Section 4.2.3 provides the step-wise calculations from the raw data until these times.

4.2.1 The dashboard

Promens uses several KPIs as a base for making decisions, depending on the department within the company. The production department uses the following four KPIs: the rejection rate, the reparation rate, the emptiness rate and the realisation rate. Figure 4.1 displays the results of these KPIs over the last 14 weeks. The smiley visualises if the production group achieve the desired goal of that week, in the example week 18 of 2021.

Figure 4.1: The dashboard showing the results of the four KPIs, rejection rate, reparation rate, emptiness rate and the realisation rate. The smileys make it clear for the handlers in the hall how they performed.

The ´empty´ KPI is when the mould is not filled with powder, but still is assembled on the machine. This might be due to a malfunction in the mould, or when the product is rejected multiple times. The 'empty' KPI is determined by:

$$\text{´}empty\text{´}\ KPI = \frac{number\ of\ empty\ moulds\ through\ the\ cycle}{the\ gross\ production} * 100\%$$

The goal for this KPI is that the maximum allowance of the 'empty' KPI is 1.5%.

The 'rejection' KPI represents the ratio of the products that are not accepted and not repairable anymore, for example because the walls are too thin, there is a spot in a different colour on the product or the screw threat from the product does not work properly. The 'rejection' KPI requires the net production amount, from which the calculation is:

$$Net\ production = gross\ production - empty\ amount\ of\ moulds$$

Then, the calculation of the 'rejection' KPI is:

$$'Rejection'\ KPI = \frac{number\ of\ products\ rejected}{the\ net\ production} * 100\%$$

The maximum allowance for the 'rejection' KPI is 1.5%.

The 'reparation' KPI contains the products that come wrong out of the machine, but are still possible to be manually fixed. Fixing mainly involves having a rod of plastic and melting it to the products on places where an undesired gap is. The calculation of the 'reparation' KPI is as follows:

$$'Reparation'KPI = \frac{number\ of\ products\ repaired}{the\ net\ production} * 100\%$$

The maximum allowance for this KPI is 1.2%.

The 'realisation' KPI is the most interesting KPI, because this displays all the ratio products that are ready for the customer. A planner upfront in the office determines the production plan, which resembles the expected output. The total correct by machine involves all the correct products coming directly from the machine. Using the following formula results in this KPI:

$$'Realisation'KPI = \frac{total\ correct\ by\ machine}{production\ plan} * 100\%$$

The minimum allowed KPI value for the realisation is 90%.

In the current calculation of the production plan, the cycle time is 84 minutes, while the cycle time in reality is 75, causing the 'realisation' KPI to be higher than 100%, which is not realistic anymore. The following calculation provides the actual 'realisation' KPI:

$$Wrong\ 'realisation'\ KPI\ /\ \left(\frac{old\ cycle\ time}{new\ cycle\ time}\right) = 102.5\%\ /\ \frac{84}{75} = 91.5\ \%$$

Shows the average results over the past half year for every KPI. Calculation of the first three KPIs requires the actual amount of production, while the last KPI, 'realisation' uses the expected amount of production.

Table 4-1: The used KPIs and the average results compared to their goals. Promens is able to achieve their all of their goals regarding the production process.

KPI:	The goal:	Average result:
Empty	< 1.5%	1.0%
Rejection	< 1.5%	1.2%

Reparation	< 1.2%	0.4%
Realisation	> 90%	91.5%

Overall, Promens is able to achieve their production process goals and perform according plan. Especially, the 'reparation' KPI is far below their limit. In case the 'empty' and 'rejection' KPI lower, the 'realisation' KPI will automatically increase. Establishing these KPIs will guide the process of implementation of the new solutions, while keeping in mind the level of quality during the production process.

4.2.2 The current labour utilisation

This section provides the outcome of the analysis of the newly gathered data by combining it with the data of the production schedule.

For calculating the labour utilisation, which represents the percentage of time the employees perform activities, it requires the calculation of the waiting time rate, done with the following formula:

$$Waiting\ time\ rate = {total\ measured\ waiting\ time}/_{total\ measured\ time}$$

Then, the calculation of the labour utilisation rate at each station is as follows:

$$labour\ utilisation\ rate = 100\% - waiting\ time\ rate$$

Table 4-2 shows the outcome of the two formulas at each work station. The applied formula for validating the outcome om the labour utilisation rate is the following:

$$Validation\ rate = {the\ scheduled\ measurement\ time}/_{the\ total\ measured\ time}$$

Where the scheduled measurement time represents the time that is measured in total, for example between 13:00 and 13:30 which is half an hour, while the total measured time consists of a summation of all the smaller measured time per activity. The closer this value is to 100%, the more trustworthy the outcome of the measurements is.

Table 4-2: The established waiting time rate, followed by the calculated labour utilisation per department, the validation rate confirms the trustworthiness of the labour utilisation rate.

	Waiting time rate:	Labour utilisation rate:	Validation rate:
AWA table 17:	42.5%	57.5%	99.73%
AWA table 20:	34.2%	65.8%	99.45%
Robot 1:	6.1%	93.9%	101.44%
Robot 2:	31.3%	68.7%	100.56%
Average:	28.5%	71.5%	100.3%

Figure 4.2 visualises the standard deviation from the validation rate, with only a maximum deviation of 1.15%, meaning that the measurements are reliable.

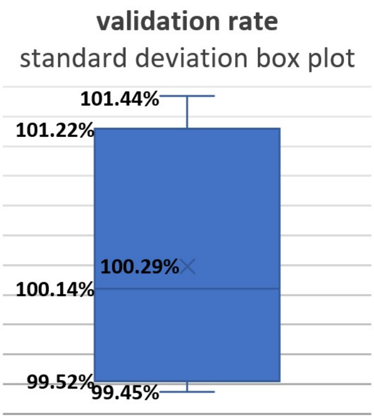

Figure 4.2: The standard deviation of the labour utilisation rate outcomes, the maximum deviation is 1.15%, which is low enough to take the measurements as being reliable.

The average labour utilisation is 71.5%. Promens strives to have the workload equally divided, or to save a handler and thereby increasing the labour utilisation. In both cases, the labour utilisation must be below 90%, so the handlers still have enough time for going to the toilet or grabbing a cup of coffee next to their job. In the current situation, there is a big difference between the labour utilisation of the AWA tables and Robot 2 compared to Robot 1, which has a utilisation rate that is actually too high.

4.2.3 The required working time per activity during one shift

The gathered data contains information regarding the activities performed and the time they require, needed for rearranging the tasks for improving the labour utilisation. The following stepwise approach guides in calculating the required working time per shift for each activity. The first step is to calculate the expected product output at every machine and workstation, whereafter the performed measurements help in determining the required time for handling one product at a certain station. Multiplying this time with the expected output results in the required time per activity at each workstation during one shift.

The input variables

Observation establishes the amount of moulds on every machine and the ratios between the amount of products passing the robots or not. There are two types of packaging methods: pallets and boxes. Depending on which station the product comes from, there is a different ratio between the pallets and boxes. The production cycle time is the time it takes for one mould to make a full round over the machine and deliver one product. The machines keep producing during the break of the handlers, not subtracting these results in a shift length of 8.5 hours. The realisation is the percentage of products passing through the whole production process. The realisation splits up in realisation at the machine, known as the ´empty´ KPI, and realisation at the AWA tables and robots, also known as the KPIs ´reparation’ and ‘rejection’. Section 4.2.1 elaborates further on the KPIs. For now, both are set on 100%, because even when a product does not pass the whole chain, it still requires effort and time to process differently and this cannot be neglected. Table 4-3 shows an overview of all the determined variables.

Table 4-3: the input variables for the calculations, observed during the measurements. They are divided in the categories production route, production environment and realisation KPI. The 'M' symbolizes the rotational moulding machines.

Production route variables:	Average products:
Number of moulds on M17:	12
Number of moulds on M20:	12
Number of moulds on M21:	8
From M17 & M20 to Robot 1:	0
From M17 & M20 to Robot 2:	12
From M21 to Robot 1:	7
From M21 to Robot 2:	1
Avg products per package M17 & M20:	10
Avg products per package M21:	0
Avg products per package Robot 1:	3
Avg products per package Robot 2:	24
Avg boxes as packages M17 & M20:	1/6
Avg boxes as packages M21:	0
Avg boxes as packages Robot 1:	0
Avg boxes as packages Robot 2:	3/8

Production environment variables:	
Production cycle (minutes):	75
Shift length (hours):	8.5
Number of shifts per week:	9

Realisation KPI:	
Rotational machines / KPI 'empty':	100.00%
AWA tables + robots / KPIs 'reparation' & 'rejection':	100.00%
Total:	100.00%

Calculation of the expected outputs of the rotational moulding machines

Calculation of the expected outputs of the several rotational moulding machines during one shift requires to first calculate the expected output per hour by using the following formula:

$$Output\ per\ hour = \ number\ of\ moulds\ on\ machine\ X * \left(\frac{60\ minutes}{production\ cycle}\right)$$

The next formula calculates the output per shift:

$$Output\ per\ shift\ = \ output\ per\ hour * shift\ length * machine\ realisation$$

Whereafter it follows that the output per week is:

$$Output\ per\ week = output\ per\ shift * number\ of\ shifts$$

The output per day is an average over the week, because Friday only has one shift.

$$Output\ per\ day = output\ per\ week / \ 5$$

Table 4-4 displays the results of the calculations regarding the outputs over several time frames per rotational moulding machine.

Table 4-4: the product output per machine during several time frames. Machine 21 produces bigger products, so less moulds fit.

	Expected output per hour:	Expected output per shift:	Expected output per week:	Expected output per day (average):
Machine 17:	9.6	81.6	734.4	146.9
Machine 20:	9.6	81.6	734.4	146.9
Machine 21:	6.4	54.4	489.6	97.9
Total:	25.6	217.6	1958.4	391.7

Calculation of the expected outputs of the workstations

Table 4-3 shows the intensity of flow between the different workstations that helps for calculating the output per workstation. Starting with the determined output of the machines, the following formula helps determining the output of AWA in one shift:

$$AWA\ table\ X\ output\ per\ shift = Machine\ X\ output\ per\ shift * (1 - (ratio\ 'M17\&20\ to\ Robot\ 2'\ )) * AWA\ realisation$$

Where:

$$Ratio\ 'M17\&20\ to\ Robot\ 2' = \frac{'from\ M17\ \&\ M20\ to\ Robot\ 2'}{(M17\ 'output\ per\ shift' + M20\ 'output\ per\ shift')}$$

The formula for the output of the robots is slightly different, but built with the same concept:

$$Robot\ X\ output\ per\ shift = (output\ M17\&20 * ratio\ to\ Robot\ X + output\ M21 * ratio\ to\ Robot\ X) * AWA\ realisation$$

The calculation of the expected output per week and per day follows the same formula when calculating these outputs of the machines. Calculating the number of times that packaging is required is done with the average products per package in the following formula:

$$Expected\ packaging\ per\ day = \frac{expected\ output\ per\ day}{avg\ products\ per\ package}$$

From this expected packaging per day at each workstation, the number of packaged boxes follows from the following formula:

$$Expected\ boxes\ per\ day = expected\ packaging\ per\ day * avg\ boxes\ as\ packages$$

provides the results of these formulas at every workstation.

Table 4-5: The expected product output and packaging output at each workstation during several time frames.

	Expected output per shift:	Expected output per week:	Expected output per day (average):	Expected packaging per shift:	Expected boxes per shift:
AWA table 17:	40.8	367.2	73.4	3.9	0.7
AWA table 20:	40.8	367.2	73.4	3.9	0.7
AWA table 21:	-	-	-	-	-
Robot 1:	47.6	428.4	85.7	17.9	-
Robot 2:	88.4	795.6	159.1	3.7	1.4
Total:	217.6	1958.4	391.7	29.5	2.7

The required time per product per activity at every workstation

The performed measurements provide information about the amount of time it takes to perform one activity with a product. The following formula sums for every activity within each workstation the required time over all measurements.

$$\begin{aligned}&\textit{The required time for activity } Y \textit{ at workstation } X \textit{ during all measurements}\\ &= \sum_{\textit{workstation } X} \sum_{\textit{activity } Y} \textit{required time during all measurements}\end{aligned}$$

Where $X = [AWA\ table\ 17, AWA\ table\ 20, Robot\ 1, Robot\ 2]$ and $Y = (1{,}16)$

During the measurements, not all products were finished and these shall not be divided with. The next formula subtracts the non-finished products:

$$\begin{aligned}&\textit{Number of products finished during measurements}\\ &= \textit{number of products during measurements}\\ &- \textit{number of products not finished during measurements}\end{aligned}$$

The calculation of the average required time per product per activity at every workstation is a combination of the outcome of the previous two formulas:

$$\begin{aligned}&\textit{The required time per product with activity } X \textit{ at station } Y\\ &= \textit{ the required time for activity } Y \textit{ at workstation } X \textit{ during all measurements}\\ &/\ \textit{number of products finished during measurements}\end{aligned}$$

Table 4-6 shows for every activity at every station the total measured time and the average required time per product. Not every product requires all activities, but is still divided by all the products passing that workstation. Therefore, some required times per product are quite low. However, this does not influence the validity of the final outcome, because by multiplying this low required time per product with the expected total output of that workstation, the total required time of that activity is correct.

Table 4-6: The total measured time for each activity at every workstation. dividing it with the number of products completely followed, results in the average required time per product at every workstation. The activities from the packaging, step 17 onward, require a different method of calculation and are therefore empty.

	(hh:mm:ss)	AWA table 17:		AWA table 20:		Robot 1:		Robot 2:	
	Activity:	17	Avg per product:	20	Avg per product:	R1	Avg per product:	R2	Avg per product:
1	Next to other products on table	-	-	-	-	-	-	-	-
2	Trim edges	00:23:45	00:01:15	00:27:30	00:01:37	-	-	-	-
3	Quality check	00:07:55	00:00:25	00:13:45	00:00:49	-	-	-	-
4	Cooling	-		-	-	-	-	-	-
5	Drill holes	00:04:25	00:00:14	00:04:05	00:00:14	-	-	-	-
6	Bring to cooling	00:00:40	00:00:02	00:02:30	00:00:09	-	-	-	-
7	Cooling	-		-	-	-	-	-	-
8	Clamp product	-		-	-	00:06:50	00:00:41	00:23:40	00:00:31
9	Robot drills	-		-	-	-	-	-	-
10	Remove scrap pieces	-		-	-	00:02:45	00:00:16	00:13:35	00:00:18
11	Unclamp product	-		-	-	00:03:55	00:00:23	00:15:30	00:00:20
12	Go from Robot to AWA table	-		-	-	-	-	-	-
13	Clean product	00:05:30	00:00:17	00:03:45	00:00:13	00:03:45	00:00:23	00:18:30	00:00:24
14	Assemble parts	00:13:35	00:00:43	00:05:40	00:00:20	00:40:55	00:04:05	00:25:10	00:00:33
15	Flame product	00:05:55	00:00:19	-	-	-	-	00:10:40	00:00:14
16	Bring product to pallet	00:06:10	00:00:19	00:04:40	00:00:16	00:02:45	00:00:16	00:17:15	00:00:23
17	Seal by hand / banding / plastic								
18	Go to sealstation								
19	Sealstation								
20	Pallet to expedition								
21	Grap new pallet								
22	Grap new carton box								
	Number of products during measurements:	29		23		13		62	
	Products not finished:	10		6		3		16	
	Products finished:	19		17		10		46	

The required time of the extraordinary activities

Next to the regular tasks, the handlers perform extraordinary activities, that are not easy to connect to the production of one product. These are: cleaning the working place, performing the packaging task and, for the robots, changing the jiggs. The jiggs hold the products when the robot performs work on it.

The measured packaging time involves the time the employee needs for performing the complete packaging activity. It also excludes the time the seal station itself is busy, because during that time the handler can and is performing other tasks. Table 4-7 shows the established time when summing the activities 17 till 22 and taking the average at every workstation involved in packaging.

Table 4-7: The required packaging time for a pallet or a box for every workstation and its average over all the workstations.

Packaging times:		
Workstation:	Pallet: (hh:mm:ss)	Box: (hh:mm:ss)
AWA table 17/20:	0:06:43	0:04:35
Robot 1:	0:06:57	-
Robot 2:	0:07:07	0:08:30
Average:	0:06:56	0:06:32

The handlers clean their work place at the end of every shift. Table 4-8 shows the average measured cleaning time for every workstation.

Table 4-8: The average cleaning time from the workplace for every workstation and that total cleaning time.

Cleaning the workstations:	
Workstation:	Average: (hh:mm:ss)
AWA table 17/20:	00:06:55
Robot 1:	00:12:30
Robot 2:	00:21:35
Total cleaning time per shift:	**00:47:55**

An extra activity for the robots is to replace the jiggs when new products come out of the rotational moulding machine and need to pass the robot. Both robots require this activity around twice per shift. Table 4-9 shows the time of switching a jigg once and what it takes during a full shift for every robot.

Table 4-9: The average time of changing one jigg and the total time it takes in one shift at the every robot workstation.

Changing jiggs:		
Workstation	Replacing one jigg: (hh:mm:ss)	Total time per shift: (hh:mm:ss)
Robot 1:	00:12:00	00:24:00
Robot 2:	00:03:00	00:06:00
Total changing time jiggs per shift:		0:30:00

The required time per activity per shift at each workstation

The calculation of the complete required time per activity during one shift at every workstation requires the outcomes of the previous taken steps. The following formula provides the required work time per shift for the first six steps:

$$Work\ time\ per\ shift\ per\ activity = avg\ time\ per\ product\ AWA\ table\ X\ * output\ Machine\ Y$$

Where X is workstation AWA table 17 or AWA 20, because only these handle the first six activities. Activity seven is not an activity for the handler, but for the product that is cooling down. After activity seven, there is a division between the products being processed further at the robots or at the AWA tables. The next formula calculates the required work time for activity eight till sixteen:

$$Work\ time\ per\ shift\ per\ activity = avg\ time\ per\ product\ workstation\ \mathrm{X} * output\ workstation\ \mathrm{X}$$

Activity seventeen till 22 relate to the packaging department. Due to having two types of packaging, pallets and boxes, it requires a different calculation:

$$Packaging\ time\ workstation\ \mathrm{X}\ per\ shift = (total\ packaging - boxes) * pallet\ time\ workstation\ \mathrm{x} + (boxes * box\ time\ workstation\ \mathrm{x})$$

Table 4-10 shows the combination of these work times per activity during a shift for every workstation together with the extraordinary activities, which results in the total time a handler at a workstation needs. the following formula uses the determined labour utilisation rates in Section 4.2.2 and validates whether the calculated results are realistic:

$$Expected\ outcome\ working\ hours\ =\ labour\ utilisation\ workstation\ X * 7{:}45{:}00$$

A small difference between the expected outcome working hours and the calculated average working hours validates whether the outcomes of the previous formulas are realistic and the working hours are acceptable.

Table 4-10: The required time an activity takes during one shift for every station and all stations together. The validation checks whether these times are realistic with the earlier established utilisation rates. The lower the percentage, the closer the calculations are with the measurements.

Required work time per shift: (hh:mm:ss)	**Total of all workstations:**	AWA table 17		AWA table 20		Robot 1		Robot 2	
		Required time:	Output rate:	Required time:	Output rate:	Required time:	Output rate:	Required time:	Output rate:
1 Next to other products on table	-								
2 Trim edges	**03:54:00**	01:42:00	M17	02:12:00	M20				
3 Quality check	**01:40:00**	00:34:00	M17	01:06:00	M20				
4 Cooling	-								
5 Drill holes	**00:38:34**	00:18:58	M17	00:19:36	M20				
6 Bring to cooling	**00:14:52**	00:02:52	M17	00:12:00	M20				
7 Cooling	-								
8 Clamp product	**01:18:00**					00:32:32	R1	00:45:29	R2
9 Robot drills	-								
10 Remove scrap pieces	**00:39:12**					00:13:05	R1	00:26:06	R2
11 Unclamp product	**00:48:26**					00:18:39	R1	00:29:47	R2
12 Go from Robot to AWA table	-								
13 Clean product	**01:14:13**	00:11:49	AWA 17	00:09:00	AWA 20	00:17:51	R1	00:35:33	R2
14 Assemble parts	**04:45:54**	00:29:10	AWA 17	00:13:36	AWA 20	03:14:46	R1	00:48:22	R2
15 Flame product	**00:33:12**	00:12:42	AWA 17					00:20:30	R2
16 Bring product to pallet	**01:10:41**	00:13:15	AWA 17	00:11:12	AWA 20	00:13:05	R1	00:33:09	R2
17 Seal by hand / banding / plastic bag									
18 Go to sealstation									
19 Sealstation	**03:22:49**	00:25:05	AWA 17	00:25:05	AWA 20	2:04:12	R1	00:28:26	R2
20 Pallet to expedition									
21 Grap new pallet									
22 Grap new carton box									
Total time regular activities:	**20:19:53**	04:09:51		04:48:29		06:54:10		04:27:23	
Cleaning time:	**00:47:55**	00:06:55		00:06:55		00:12:30		00:21:35	
Changing jiggs:	**00:30:00**					00:24:00		00:06:00	
Total time available:	**31:00:00**								
Total time worked:	**21:37:48**	04:16:46		04:55:24		07:30:40		04:54:58	
Validation:									
Available working time:	07:45:00								
Available time * utilisation	**22:09:33**	04:27:28		05:05:48		07:16:42		05:19:35	
Difference:	**2.21%**	0.74%		0.72%		-1%		1.71%	

4.2.4 Analysis of the required time per activity at the workstations

This conclusion examines the calculated time of each activity and highlights interesting numbers. As expected, trimming the edges is one of the activities that involve the most work, because every product that comes out of the machines 17 and 20 requires these activities. The operator from machine 21 trims and performs the quality check on the products himself. Connecting and disconnecting the products from the quality control machine takes in total one hour and forty minutes. Different shapes and sizes cause the difference in time between the two AWA tables. Drilling the holes by hand takes 38 minutes per shift, due to the fact that are being drilled by the machine instead of the handlers. Bringing to cooling takes in total around 15 minutes. AWA 17 has a double advantage, because, during the measurements, it had less products that went to the robot and the cooling tables are much closer.

Clamping the products in the robot takes 1 hour and 20 minutes in total. The difference in time between R1 and R2 is because the output at R2 is higher than at R1. R1 has less cells and the products take longer to get ready. The same counts for removing the scrap pieces and unclamping the products. Those two take approximately 40 and 50 minutes in total.

Cleaning the product takes 1:16 hours in total and depends per workstation on the amount of products that passes it. A remarkable difference is seen at the assembly of the products. For AWA tables 17 and 20, this mainly involves screwing lids on the products, while R1 often needs to screw iron on the products, which takes more time and R2 processes more products than R1. Flaming the product at AWA 17 and R2 takes 33 minutes in total. Bringing the product to the pallet is for AWA 17 and 20 almost the same time, because the pallets are standing in the middle and in front of them. R1 has the pallets standing the closest, which is why bringing the product to the pallet is not much work, compared with its output. The packaging in total takes 3 hours and 22 minutes, which is almost half a shift. The packaging of R1 is much higher, because on average only three products fit on one pallet.

Summing all the different required times gives a total required time of 22 hours and 10 minutes. Currently, there are four handlers each working 7 hours and 45 minutes, in total 31 hours. Multiplying this 31 hours with the goal of the company to have the utilisation between 80% and 90% results in 26 hours being effective. The difference between those two is 4 hours, which is almost half a shift.

Shows the overview of the current division of tasks, the time it requires, the utilisation rates and the required number of handlers. The formula for the utilisation rate of the calculated required times is:

$$Utilisation\ rate\ of\ the\ calculated\ times = the\ required\ time\ /\ 7{:}45{:}00$$

Where 7:45:00 is the number of hours the employees work without the breaks.

Table 4-11: An overview of the current division of tasks, the total time it requires, the utilisation rates and the required number of handlers. The utilisation at Robot 1 is too high, while the others are really low.

Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate: (hh:mm:ss)	Number of handlers: (hh:mm:ss)
AWA table 17:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	04:16:46	55%	1
AWA table 20:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	04:55:24	64%	1
Robot 1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
Robot 2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
Total:		**21:37:48**		**4**

4.3 Observation suggestions

By performing observations, new improvement ideas come up. The categorization of these ideas is with the following sections: the robot times, the safety, ergonomics and sustainability, the handling effort and the cleaning time.

4.3.1 The robot times

It turns out that they do not use the machines on full capacity. Table 4-12 shows the time they stand still and the utilisation rate of, gathered from measurements.

Table 4-12: The robot utilisation rates, both are lower than the company envisions.

Robot utilisation:			
Workstation:	Total time measured: (hh:mm:ss)	Time the robot stands still: (hh:mm:ss)	Robot utilisation rate:
Robot 1:	01:03:00	00:14:50	76.5%
Robot 2:	02:55:00	01:17:55	55.5%
Average:			66.0%

Robot 1 has a utilisation rate of 76.5%. Depending on the product, the robot needs around five minutes for finishing the product. Together with the clamp and unclamp times, provided in section 4.2, the time it takes for one product is: 5 minutes + 41 seconds + 23 seconds, 6 minutes and 4 seconds. Theoretically, around nine products per hour should come out of the robot. In reality, around six to seven products come out of the machine. It turns out that the robot is only stands still for a remarkable longer time when the handler of the robot needs to package his full pallet. The following formula validates this concept:

$$
\begin{aligned}
&\textit{The percentage the Robot 1 handler is packaging} \\
&\quad = {}^{\textit{the packaging time at Robot 1}}/_{\textit{the total working hours}} \\
&\quad = {}^{2:04:12}/_{7:45:00} = 27\%
\end{aligned}
$$

Because the percentage of the Robot 1 handler is packaging (27%) is almost equal to the percentage the robot is standing still (100% - 76.5% = 23.5%), a good option is to let another handler perform the packaging. The assembly of the products takes around 4 to 5 minutes, which is almost the same time the robot needs, therefore, this can still be done by the handler at Robot 1.

Robot 2 has a utilisation of 55.5%, which is undesirable low. The robot is newer than robot 1 and works with separate cells, making it possible to clamp and unclamp while the robot is working in another cell. The time the robot requires is highly dependent on the product. According to one of the mechanical engineers, once a handler has filled all the cells, the robot has work for around 45 minutes, giving the opportunity to the handler to perform other tasks such as assembly, cleaning and packaging. So, theoretically, it is possible to increase the utilisation to around 75%. It turns out that most of the employees do not fill the robot efficiently, meaning that in case the robot is busy, the employee waits, and when the employee is busy, the robot has to wait. A suggestion for improving the robot utilisation is to have the cooling stock next to the correct cell. This is already the case at robot 1 and the advantage of this is that the stock is visualised for the handler and he can easily see how much work there is for the machine. Another advantage is that the walking distance between the cooling stock and the product is lower.

4.3.2 Safety, ergonomics and sustainability

Figure 4.3 shows one of the blue bins next to the robots where the robot handlers can discard the scrap pieces coming from the products. The forklift of the expedition department is too big to drive directly to the bins, so it also requires movement by hand. Some of the blue bins have wheels underneath it, making it easier to move them. However, most of those bins do not have the wheels anymore, so the handlers drag the bin over the floor. This is ergonomically not very responsible, because it takes more time and is heavier than it should be.

Figure 4.3: A blue bin without wheels underneath, where the scrap is disposed.

Robot 1 has some products that are too long for a regular euro pallets, which are currently placed on special pallets which are two meters long. Moving them with a regular pallet cart is difficult, because the heaviest point of the pallet is at the end of the pallet cart, making the pallet wiggle. Shows how close the middle point of the pallet is to the end of the cart. The suggestion is to buy a longer pallet cart, making the movements much easier.

Figure 4.4: The extralong pallet next to the regular sized pallet cart. The end of the pallet cart is really close to the middle of the pallet itself, making it wiggle.

A difference between the workstations AWA table 17 and 20 is that 17 changes the height of the table by using feet pedals, while AWA 20 uses buttons assembled on the side of the table. An advantage of the feet pedals is that both hands are free to use. However, according to one of the handlers, it is safer to have the buttons on the side, so the handler cannot stumble and fall. The suggestion is to replace the feet pedals with the safer option having buttons on the side.

Figure 4.5: The feet pedals for adjusting the height next to AWA table 17, making it unsafe, because of the chance to stumble.

Figure 4.6: The safer option is already present at AWA table 20, having buttons on the side of the table to adjust the height.

The employees use non-electric pallet carts, which are safer, according to the head of safety and control. On average, the products are 10 kg each and the euro pallets weight around 25 kg (EPAL, n.d.). In total, a full pallet has around 8 products and the total weight that is moved around is ± 100 kg. Moving those pallets around takes effort by the employees. Lighter pallets weighting around 2 kg and made from recyclable plastics can be used instead (DAWO, 2020). In combination with the goal to be as sustainable as possible and the rising wood prices it will help the sustainable image (Olick, 2021). Implications such as the acceptance of customers for these special pallets need to be taken a closer look at before implementation is possible.

4.3.3 Decrease the handling effort

After drilling a hole in the product, a plastic disc remains. The handlers from AWA table 17 and 20 toss this disc in a garbage bin that is standing at least two meters away, but because of the distance they sometimes miss and need to grab it. This takes time and effort which can easily be solved. The other handlers walk to the bin, which also takes time. By having two bins instead of one, they don't need to toss the plastic disc or walk after every drill.

A computer shows information to the handlers to check what products they need to finish. By clicking on a product code, information regarding that product is shown. However, the computer does not show the handling instructions, these lay printed below the computer. A suggestion is to place the handling instructions in the computer as well so the handlers can easily find it by clicking on the product, instead of searching through the box until they find the right booklet.

The handlers register the products that are finished in the computer. But due to lack of consistency in filling it in, there is a higher chance on mistakes. Being more consequent with registering the products that have passed their workstations, results in a more trustworthy production amount.

The handlers lose 20 seconds searching for a pallet cart, before it is possible to move the pallet itself. Section 4.2.3 states that 30 times per shift a pallet is packaged. From the lean perspective, this non-value adding activity takes up ten minutes every shift. Currently, there are three pallet carts, one at AWA 17 and 20, one at R1 and one at R2. But when AWA 17 and AWA 20 both have one pallet full, they need to wait for a free cart before the packaging can continue. At robot 1, an extra pallet cart will be a helpful solution as well, so there is one available at every cell, where the walking distances between the cells are quite big due to the roller conveyors.

The handlers strap the pallets by hand, which takes three minutes for every pallet. First they grab the plastic rope and a stick, so they can pass it underneath the pallet. Then, they cut and tighten it with the use of metal clamps. The strapping is on the same place as the stacking, because otherwise the products will fall of the pallets. To decrease the packaging time, a strapping machine can help out, under the requirement that all packaging activities are grouped into one place in the production hall.

Figure 4.7: the manual strapping cart, containing a plastic rope, iron clamps, a knife and plastic sticks.

4.3.4 Decrease the cleaning time

Cleaning robot 2 takes around 20 minutes every shift. The main reason for this high cleaning time is the fact that the bottom of the machine has a lot of steel bars and cables. The handler first needs to vacuum the larger scrap piles, then needs to blow the other scrap pieces away from the bars and cables, whereafter he needs to vacuum again to remove the last scrap. A simple solution for this problem is to equalize the bottom below the robot and cover the bars and cables. The cables do not produce a lot of heat and can therefore be completely closed off. The handler does not have to walk in the machine, so the weight on the cover plates is low. The material of the proposed plates can be from wood or aluminium. Besides saving time with the cleaning, it also requires less effort from the handlers. An extra suggestion is to add a few holes in the plates, so the employee can easily blow the scrap into those holes and only needs to clean those holes.

Figure 4.8: Robot 2 having scrap material between the cables and metal beams that are hard to reach.

Robot 2 has three poles around it with an air blower and a vacuum cleaner to clean from all sides, but these poles are standing in the walking paths of the handlers. The relatively simple solution for this is to make of a swivel arm on the robot frame with both cleaning tools. Appendix C shows an example of a swivel arm. Another advantage of removing the poles, is that there is space to implement the earlier solution, which is to cool the product directly next to the corresponding cell.

Figure 4.9: One of the three cleaning poles blocking the walking paths around robot 2.

Currently, the AWA tables are open and the table legs are visible. When trimming the edges of the products, the scrap flies all around the table. By closing the open sides of the table, the scrap will not go underneath the harder-to-reach places. This is simply achieved by placing curtains or plates at the side of the tables.

4.4 Chapter conclusion

The KPIs the production department uses for managing their results, are the ‘rejection’ KPI, the ‘reparation’ KPI, the ‘empty’ KPI and the ‘realisation’ KPI. Over the past half year, Promens manages to achieve its goals and the production results are according plan. The KPIs will function as the dependent variable and guide the process of reallocation of the task and implementation of the solutions. Achieving the goal of improving the labour utilisation requires knowledge about the current labour utilisation and the time several tasks take up. The labour utilisation among the workstations is not equally divided. The Robot 1 handler has too much work, while the other workstation handlers stand still quite often. Reallocating the tasks to improve the division of workload requires the knowledge of the time every activity takes.Table 4-10: The required time an activity takes during one shift for every station and all stations together. The validation checks whether these times are realistic with the earlier established utilisation rates. The lower the percentage, the closer the calculations are with the measurements. Table 4-10 provides an overview of the required time per activity during one shift. Promens can also introduce smaller improvements, starting with making better use of their robots, by keeping in mind the robot times when reallocating the tasks. Next, four safety, ergonomics and sustainability options are possible. The first one is to place wheels under the bins with scrap for easier movement. Next, using longer pallet carts with the longer pallets will ease the movements. Safety related it is a better option to make the buttons that can change height next to the tables instead of pedals on the floor. Possible options for decreasing the handling effort are having more garbage bins and pallet carts, buying a semi-automatic strapping machine and being more consequent when registering finished products. Easier cleaning at Robot 2 is possible by adding an flat bottom below the robot and having a carrousel on top of the frame with the cleaning tools, such as the vacuum cleaner and the air blower.

5 Literature study

This literature study provides answers to the following questions. First, the question is to investigate what options there are for decreasing the walking distances and thereby decreasing the walking times. Next, the SHA forms the base for the second question to see what options are available for decreasing the handling effort of the handlers.

5.1 Decreasing the walking distances

The first option to decrease the walking distances is to relocate the activities and the personnel performing them. The question arises on where to place them, also known as a Roll Allocation Problem (RAP). Mathematical models such as the Mixed-Integer Linear Programming model (MILP) can help solve this issue. Advantages of the MILP is that applying the method is clear and understandable, because of the use of branch and bound, finding a solution and investigating possible closely related solutions to check whether it is improved. A disadvantage of this method is that the constraints must be written in a linear form, making it less adaptable (Cevikcan & Durmusoglu, 2020). MILP needs clearly defined variables. Distinctions between the variables are based on the problem type (planning, scheduling or allocation), the scheduling type (shift, days off or tour), and machines (high-labour content station or medium/low-labour content station) (Gebennini, Zeppetella, Grassi, & Rimini, 2016). Assigning the operators to certain machines is done with equations concerning the degree of automation at a station and with ergonomic aspects, such as the NIOSH and the GARG measures (Gebennini, Zeppetella, Grassi, & Rimini, 2018).

Another mathematical model for relocating and thereby decreasing the walking times, is Constraint Programming (CP). Advantages of CP compared to MILP is that CP requires less variables, making the calculations faster. Especially in the case of a linear production process, CP is the better and faster option for determining the working places of the operators (Cevikcan & Durmusoglu, 2020).

Other mathematical models closely related to the previous mentioned models are the Non-Dominated Sorting Genetic Algorithm, based on population mating pool, and the Fully Polynomial Time Approximation Scheme (Sirovetnukul & Chutima, 2010), (Sedding, 2020). An addition to the several mathematical models is MONDEN, which is based on a simple allocation problem, assigning machines to operators until the cycle time is violated. Another constraint, if possible, involves avoiding workers crossing each other paths (Shewchuk, 2008).

Another analysation type is to use the idea of a big swarm. Particle Swarm Optimization with Negative Knowledge (PSONK) focuses on the idea of generating a big swarm, whereas the swarms have particles. Computing a local best and worst and global best and worst provides a new starting position. This new starting position gives a new best and worst. This continues until its finds the best solution (Sirovetnukul & Chutima, 2010). The Bee Algorithm (BA) works with the same thought, which is finding the best solution in the neighbourhood of the related options of solutions. However, BA works with random choice in the neighbourhood and increases the chance of finding new best options (Tapkan, Özbakir & Baykasoılu, 2016). Another colony algorithm is the Ant Colony Optimization (ACO). The difference between ACO and BA is that ACO gives positive and negative feedback to the previously taken step, thereby influencing the choice of the previous step and maybe changing it (Zha, & Yu, 2014).

The choice of the mathematical models is influenced by the shape of the production process, that can be linear, L- or U-shaped. Advantages of a U-shaped process compared to linear is that the input and output can be checked by the same employee. Besides that, more possibilities for allocations of the handlers arise (Ohno, & Nakade, 1997). An in-between option can be a two-sided assembly line, that has the advantage of resource minimization, reduced idle time, reduced operator requirements and improved visibility and communication (Tapkan, Özbakir & Baykasoılu, 2016).

Besides RAP, an option is to change the process equipment or processing method. An option is to bring the required components with a component rack (CR). In order to decrease the walking distances of the operators, it turns out that the CR's should not be too long, consist of small packages and should not be too deep, e.g. not the size of the EUR-pallets (Wänström & Medbo, 2009). Based on a lean thought, conveyor belts are a good addition for further reduction of movements between the different stations (Chan, & Tay, 2018). Best ways for decreasing the walking times in processes involving conveyor belts are repositioning the supplies required for assembly or to re-sequence the order in which the handlings are done (Sedding, 2020). The Kaizen theory focuses on continuous improvements in the production process, while having a cross-functional team, proper mobilization of the workforce and employee suggestion. Combining tasks will decrease the walking distance in the production area. In a packaging area, lowering the walking times can be achieved by using multiple smaller boxes, a conveyor belt and have the working table standing perpendicular to the belt (Chan & Tay, 2018).

5.2 SHA decreasing the handling effort (SHA 5 & 6)

Starting from SHA step five, it provides theoretical information regarding options for handling improvements. There is a distinction between a direct and an indirect system, whereas the direct system involves moving the products separately and directly from origin to destination. The indirect system integrates multiple products or materials and they cross the same path with the same type of equipment. Figure 5.1 shows the three types of movement systems exist, the direct system, the kanal system and the central system. The kanal system is, compared to the central system, more economical effective when the layout is irregular and the stations are more spread out.

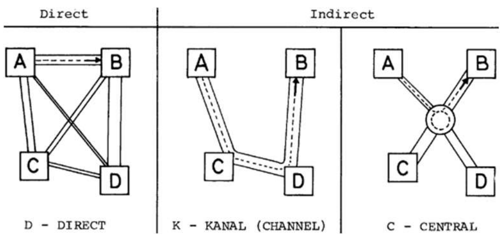

Figure 5.1: The direct movement system and the two indirect movement systems, the kanal system and central system.

A distance-Intensity plot guides in choosing the optimal layout type and handling equipment. The plot shows the relation between the distance of the different stations and the intensity of the flow. Figure 5.2 shows the link of the plot to the choice of the type of system.

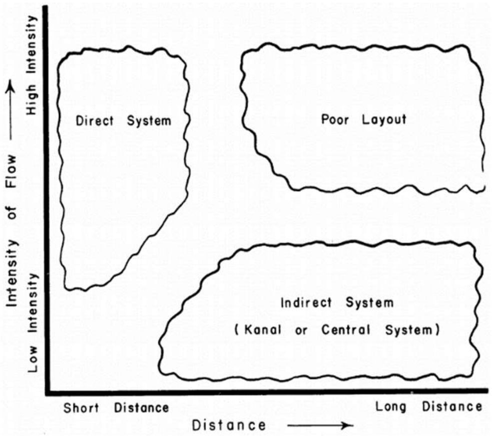

Figure 5.2: The Distance-Intensity plot for determining the type of layout system.

Figure 5.3 shows how the Distance-Intensity plot guides the right choice for handling equipment as well. The SHA distinguishes between four types of equipment: the simple handling equipment, the complex handling equipment, the simple travel equipment and complex travel equipment. The simple equipment types have a high variable direct operating cost, whereas the complex equipment types have a low variable cost.

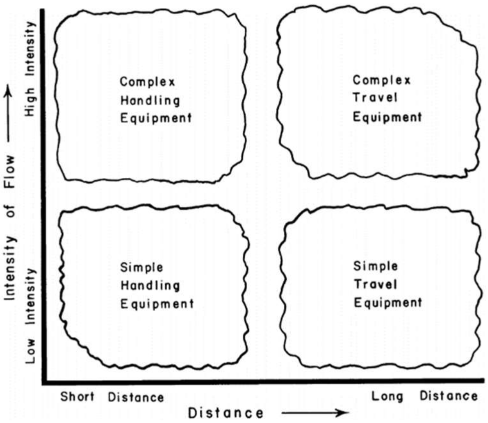

Figure 5.3: The Distance-Intensity plot for determining the type of equipment.

Several options for transporting the products are possible. Bulk handling is the simplest and cheapest methods which can be used best for products of high quantities that do not damage too quick. Individual movement is a proper option when the materials are large, have difficult shapes, are subject to damage and can easily be grabbed. Advantages of this method compared to containers is that it does not require extra operations such as loading and bundling. Container or support handling is the in-between option and mostly involve drums, cartons, boxes and the like. Because containers are bigger and heavier, it often needs methods with higher capacity. Advantages of this method is the decrease of cost-per-unit moved, because of less pick-up and set-down moments (Muther, 1969).

Figure 5.4 displays the most common models of handling equipment. Every equipment has advantages and disadvantages. The type of movement system, layout system and handling equipment will lead to a proper choice of material handling equipment.

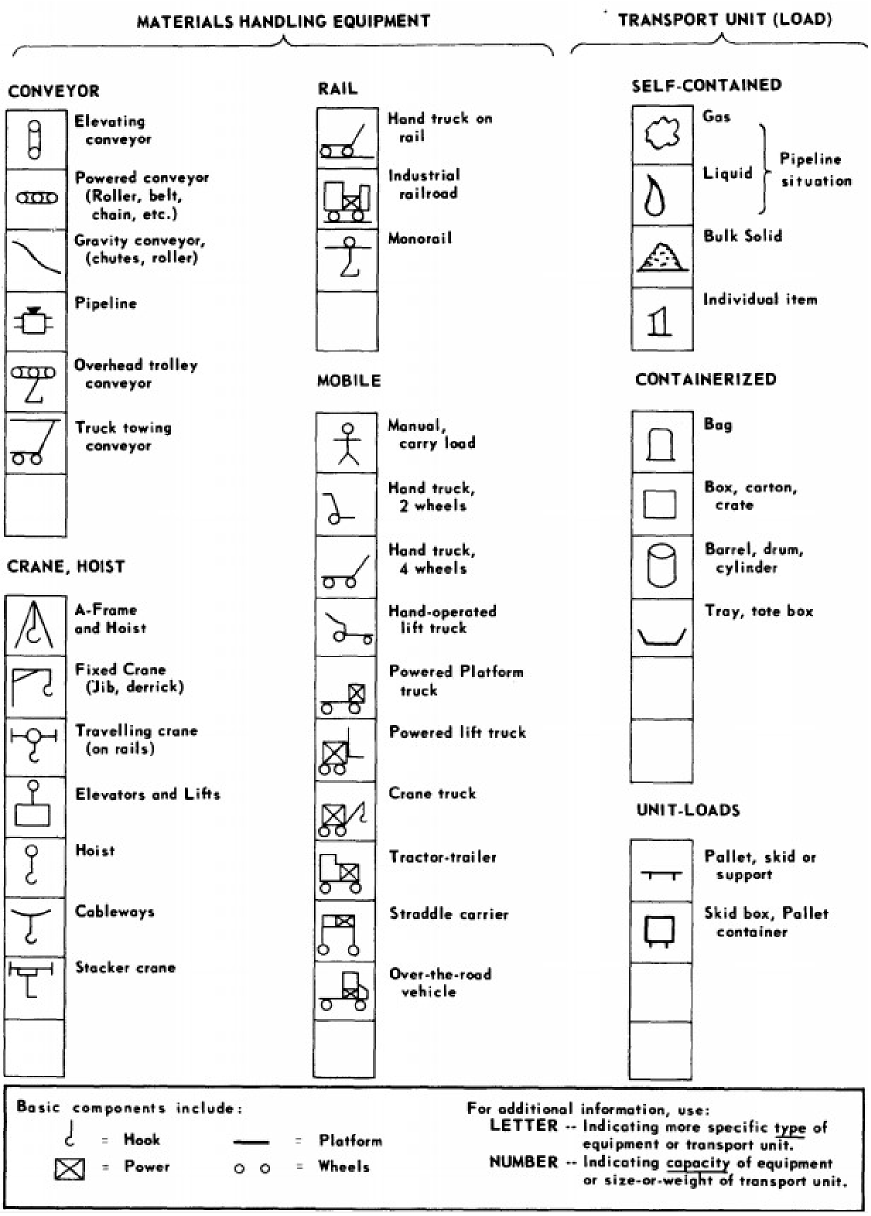

Figure 5.4: Several types of material handling equipment shown with their corresponding logos.

Further specification of the types of equipment requires in-depth research. Table 5-1 provides a clear overview of the characteristics of the movements and its surroundings to choose the most efficient handling equipment (Kay, 2012).

Table 5-1: Table to make a funded choice for the type of handling equipment, depending on the characteristics of movements and the surrounding of the production process.

Path	Fixed			Variable		
Area	Restricted			Restricted		Unrestricted
Frequency	High	Low		High	Low	—
Adjacent	—	Yes	No	—	—	—
Equipment Category	*Conveyor*	*Conveyor*	*Industrial Truck/Crane*	*Industrial Truck*	*Crane*	*Industrial Truck*

For the rest of this literature research, the focus lies on the conveyors due to the characteristics of the production Process at Promens, which are having a fixed path between the stations and a high flow frequency.

There are different types of conveyors. Figure 5.5 shows an inference chain, making the choice for a certain type of conveyor easier. appendix C shows images of the different conveyors.

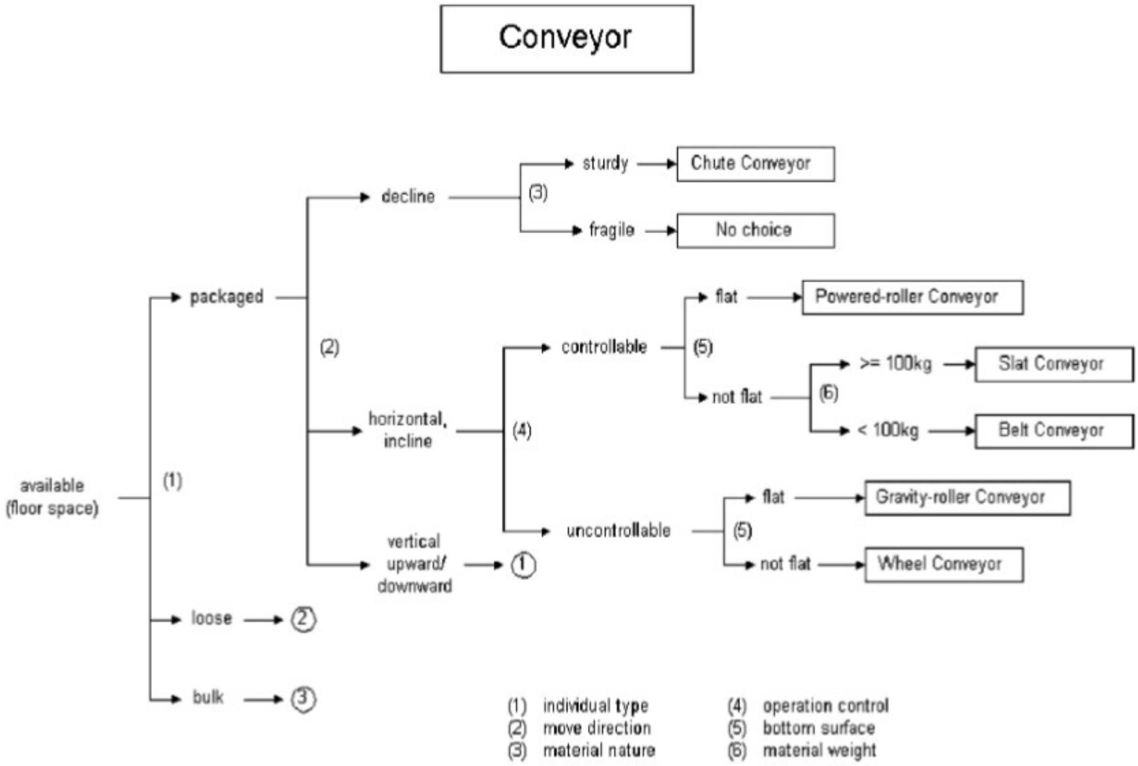

Figure 5.5: A inference chain for choosing the correct type of conveyor, fitting in the production process.

There are some differences between a gravity-roller conveyor and a wheel conveyor. Advantages of having the bigger rollers at the gravity-roller is that the products will not get stuck that quick and can have more weight. Disadvantages of the gravity-roller conveyor is that the product should not be wider than the rollers themselves and the products are more slowed down (Next level, 2013).

5.3 Literature conclusion

This literature research mainly focusses on decreasing the handling effort of the employees. The idea of MILP in combination with CP and MONDEN forms the base for the new models by reallocating the tasks among the employees. Whereas MILP gives opportunities by moving tasks around, CP and MONDEN provide constraints related to the production process and task division possibilities. Some of those constraints relate to the wishes of the problem owner, such as having the utilisation rate between 80% and 90%, or to literature suggestions, such as not letting workers cross paths. The component rack (CR) Promens uses for the assembly parts, should not be too large, too long or have too many products on it. Achieving optimal use of the workforce requires a high flexibility among the staff and active improvement input.

The SHA provides a stepwise approach for picking the proposed type of handling equipment. Determining the correct type of layout (direct, kanal or a central system), the correct type of handling equipment (simple or complex) and the correct amount of product handling (bulk, support handling or individual) guides in choosing the best fitting handling equipment. It turns out that the best type of handling equipment for Promens is a conveyor. The type of conveyor depends on factors such as the amount of product handling, the moving direction, the product characteristics, such as material, weight and bottom surface, and how to operate the conveyor. This gathered knowledge forms the base for chapter six to form several solutions.

6 solution

This chapter starts with determining the right choice for the layout system and handling equipment. The next section provides a list of the restrictions and requirements of the production process.

6.1 Advised layout system and equipment

Promens produces products that classify as one-material process. It applies the lean concept in combination with the one-piece flow strategy, which results in a high flow intensity in hall one. The distances between the workstations vary quite a lot. The rotational moulding machine, the AWA table and robot 2 are close to each other. The distance between Robot 1 and these stations is higher, resulting in more handling work for the employees.

The choice between the direct movement system or the indirect moving system depends on the flow intensity and the distance. Figure 6.1 visualises this current situation at Promens by the use of the distance-intensity plot. Because of the high flow intensity, the best choice is to make use of a direct system.

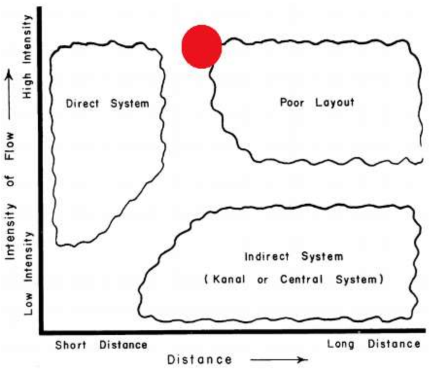

Figure 6.1: Promens and the advised type of layout system.

Figure 6.2 shows how the distance-intensity plot functions as a guide regarding the right choice of handling equipment as well. For Promens, the best option is the complex handling equipment, which has a low variable (direct operating) cost, with equipment designed for a quick and easy pick-up and set-down on shorter distances.

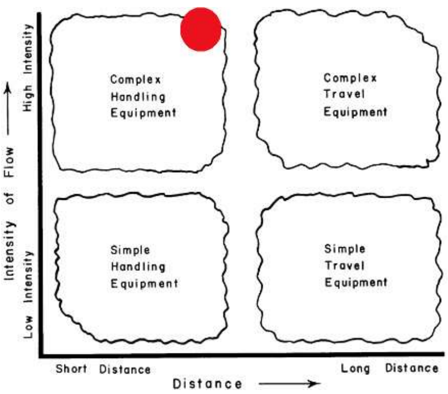

Figure 6.2: Promens and the advised type of equipment.

Establishing the type of system and the type of equipment forms the base for the choice between several handling equipment types and the change in workload at the different stations. Section 5.2 states that conveyors are of most interest for the production process at Promens, because of the fixed paths between the workstations, the restricted area in production hall one and the high frequency of the products passing due to its one-piece flow strategy. The type of conveyor depends on the placement spot of the conveyor in the production process. The main goal is to improve the labour utilization of the employees. The reparation employee, also present in hall one, has on average half a shift left for other tasks than reparations that can be used for helping the handlers with their regular tasks.

6.2 Restrictions and Requirements (SHA 7)

This section focuses on identifying the limitations present in the situation. Step seven of the SHA provides a list containing the types of limitations, restrictions and requirements to keep in mind while forming the solutions.

6.2.1 Types of modifications and limitations

There are two types of problems to take into account: the organization and personnel, and the procedures, scheduling, communications and control. The organization and control involve the limitations with respect to possible handling locations, the supervisors of the handlers, the personnel practices, the hours they are allowed to work, etc. The procedures, scheduling, communications and control involve limitations with regard to day-to-day scheduling, personnel scheduling, paper work procedures, reporting and cost efficiency control.

Some modifications or limitations are applicable in almost every project. These involve:

- Production requirements today and its long-range plan.
- Integration with the production process or process equipment.
- Services that support the handling plans.
- The layout and its space limitations.
- The building itself.
- The storage practices and equipment.
- Limited capital-investment funds.
- The project schedule itself.
- Quantities of existing handling equipment and containers.
- Equipment and transport units.
- Safety of the workers.
- The quality of the material.
- Operating policies.
- Availability and reliability of repair service and spare parts.

There are five types of planning to handle the products. The first option is letting the handler plan the handling activities completely himself. The next option is to give a sign when the products can be moved. Next, a dispatcher coordinates the handling activities after receiving information from the different stations. Another option is that a fixed schedule is followed. The last option is to integrate the movements between stations with the production of the products, for example with the use of a (electric) conveyor belt.

6.2.2 Promens' modifications and limitations

In the past years, the company decreased the variability between their products and over 70% of their products are regular and almost equal to each other. As a result, the production process is easier leading to less complex limitations. The production process involves a lot of work done by hand. Therefore, all proposed handling methods should be reachable for the personnel. Hall one has a lot of spare space in the back. On the other side, the space at the AWA tables and the robots is limited, both shall be taken into account. A lot of equipment is already attached to the ceiling, making it more difficult to attach handling equipment next to it. Possible budget limitations depend on the positive impact of the solutions.

Because the project only takes ten weeks, the proposed handling methods will not be executed on time to reflect on it. The choice for first listing the different limitations before proposing the possible improvements, will prevent waste of time by making unrealistic solutions. The grounded assumption is made that there is no limit on the handling equipment, because all movements, expect for the pallets, are done by hand. A proposition for buying new equipment is acceptable, because the currently used equipment is budgetarily low.

Promens has the safety from its personnel as number one priority. Recently, multiple improvements were introduced for contributing to that priority, such as safer knifes and strong guidance rails along the fork lift paths. The products need to remain clean. Therefore, the whole production hall shall remain clean, so no dirt is allowed to go into the moulds before the rotational process starts. In other words, handling equipment close to the moulds is not desirable. The products are made from plastic, which is not environmentally friendly. Therefore, the goal is to reuse as much scrap as possible as result from finishing the product. The scrap needs to be clean, so it can go back to the grinding room. The supervisors handle the operating policies and guide the handlers. The movement of the assembly parts and the repair department do not belong to the regular tasks of the employees and are therefore not involved.

6.3 Possible new task divisions

The Robot 1 task division is the starting point for all possible solutions, to increase the robot utilisation while improving the labour utilisation. Next to that, there are two principles for rearranging the tasks. The first solution involves removing tasks at AWA 17&20 until there work for no more than one employee. The second solution involves combining the AWA handlings from Robot 2 with the handlings from AWA 17 & 20. All options are discussed in this paragraph. The utilisation rates in this section are calculated by:

$$Utilisation\ rate = \frac{total\ hours\ of\ work\ from\ the\ activities}{7\ hours\ 45\ minutes}$$

Where 7 hours and 45 minutes is the working time of one employee without the three 15 minutes breaks. By introducing roller conveyors, the expectation is that the walking and stacking times will decrease. Because the exact positive impact of those roller conveyors is unknown, those times will not be changed.

6.3.1 The Robot 1 solution

In the current situation, the labour utilisation level at Robot 1 is too high, causing the robot utilisation level being too low. Because the time the robot is standing still is equal to the packaging time, the best option is to remove the packaging workload, thereby decreasing the too high labour utilisation and increasing the robot utilisation. There are multiple methods to establish this.

1. The first option is to have place for at least two pallet for having a buffer. This way, the robot handler has enough space to pack his products in case one pallet is being packaged or full.
2. Another option is to add two roller conveyors, one at each side of the robot, for the handler to place the finished products on. Placing the products on the conveyor is no extra effort and the amount of finished products is visualised, making it easier to see whether there are

enough products to package one pallet. The handler performing the packaging task then only has to grab a pallet, can stack it and drive away to the packaging area.

Table 6-1 shows the current utilisation rate, whereafter the new utilisation rates are given when tasks are removed.

Table 6-1: The current utilisation rate of Robot 1, compared to the two new options. First option is to remove packaging, no extra roller conveyors are required. The second option is without package and stacking, with the use of two extra roller conveyors.

Workstation Robot 1:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%
1. new:	No package	05:26:28	70%
2. new:	No package & no stack	05:13:22	67%

By decreasing the utilisation rate, there is more space for increasing the utilisation of the robot. In reality, because more products are able to pass by the robot, the labour utilisation rate will increase equally with the utilisation rate of the robot. The choice for Robot 1 solution one or two depends on the division of tasks at the other workstations.

6.3.2 Solution 1: removing activities at AWA 17 & 20 until one handler is required

The principle for establishing solution one is to remove tasks from AWA 17&20 until it requires only one handler and divide these tasks over the other handlers, together with the principle of removing tasks at Robot 1. Table 6-2 shows the required time and utilisation rate in the current situation and after every time one task is removed.

Table 6-2: The current utilisation rate of AWA 17&20 together, compared to the final utilisation of solution 1. Several activities are removed until the desired labour utilisation level is reached.

Workstation AWA tables 17&20:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%
	No package	08:21:59	108%
	No package & stack	07:42:41	100%
	No package, stack & flame	07:29:59	97%
Solution 1:	No package, stack, flame & assembly	06:47:13	88%

The strategy is to remove the last tasks first to reach the desired level of utilisation rate, which is between 80% and 90%. The first step is removing the packaging task, which results in a required time of 8 hours and 22 minutes, still too high for only one handler. By removing the task of walking to the pallet and stacking the products, the new utilisation level lowers to 100%. Removing the last two tasks, flaming and assembly, the required time remains 6 hours and 47 minutes and a utilisation level of 88%, which is low enough for one person handling the products.

By removing the packaging task at robot 2, the handler has a low utilisation rate and a lot of time left. Therefore, he takes over the removed tasks from AWA 17&20, resulting in a new utilisation rate of 78%. Table 6-3 shows the new utilisation rate from robot 2 in solution 1.

Table 6-3: The current utilisation rate of Robot 2, compared to solution 1, which involves removing the packaging task and adding the flame, assembly and stacking tasks from AWA table 17&20, resulting in a labour utilisation of 78%.

Workstation Robot 2:	The tasks:	The required time:	Utilisation rate:
Current situation:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%
	No package	04:26:31	57%
Solution 1:	No package, + all flame, assembly & stack from AWA 17&20	06:01:18	78%

One handler performs all the packaging activities from AWA 17&20, Robot 1 and Robot 2. Table 6-4 shows the utilisation rate when the handler only performs the packaging tasks and when the handler performs the stacking of Robot 1 as well.

Table 6-4: The utilisation rate of the newly introduced packager, in case he only performs the packaging, is beneath 45%, which is half a packager. In case he also performs the stacking of Robot 1, the utilisation rate becomes too high for only one packager.

Workstation packaging:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	-	-	-
Solution 1:	All package	03:22:49	44%
	All package + stack robot 1	03:37:22	47%

The utilisation rate of 47% is too high to have only one packager. The best option is to let the packager only package the products, instead of also stacking the products of Robot 1. In that case, one packager is enough. The consequence is that Robot 1 handler has to package the products on the pallet himself, resulting in a labour utilisation of 70% for Robot 1.

Table 6-5 provides an overview of the task division and the comparison between the old utilisation rates and new utilisation rates.

Table 6-5: Solution 1, the overview of the new division of tasks, the old utilisation rate is compared with the new utilisation rate. Some of the tasks are moved from one workstation to another workstation. The new utilisation rates are more equal than the old utilisation rates, meaning a better division of tasks is achieved.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
	R2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
	Packager:	-	-	-	-
	Total:		**21:37:48**		**4**
Solution 1:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean	06:47:13	88%	1
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack	05:26:28	70%	1
	R2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack + flame, assembly & stack from AWA 17&20	06:01:18	78%	1
	Packager:	All package	03:22:49	44%	0.5
	Total:		**21:37:48**		**3.5**

The new task division guides in choosing the right handling equipment. With solution one, Robot one requires two extra marked places for the empty pallets. The AWA tables 17&20 requires two extra conveyors for guiding the products to the correct station. Figure 6.3 visualises the positions of these new handling equipment.

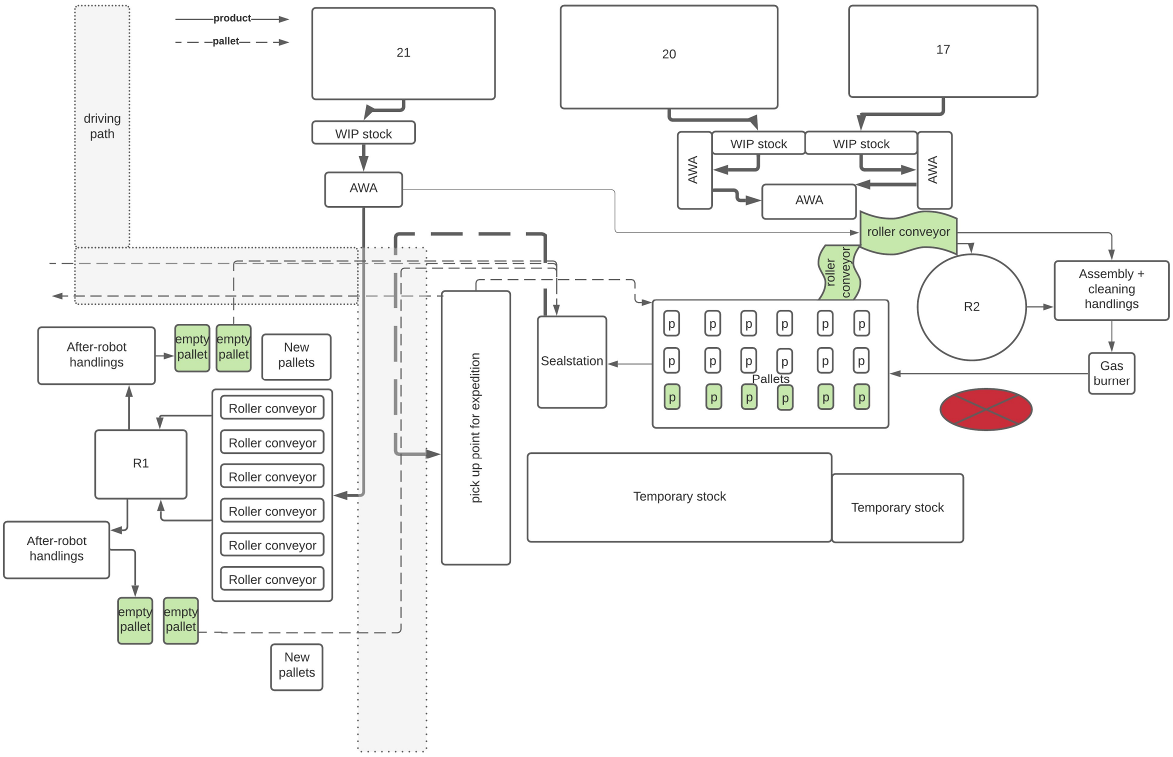

Figure 6.3: Solution 1 visualised. The Green parts are new, the Robot 1 handler stacks the products himself. The AWA tables and Robot 2 require two new roller conveyors.

6.3.3 Solution 2: moving all AWA tasks from R2 to AWA17&20 where AWA performs the packaging tasks

Solution 2 has a different approach. Here, the main goal is to combine the AWA handlings and packaging tasks from table 17, 20 and Robot 2, so Robot 2 has time left to perform other activities. Table 6-6 shows the new utilisation rate in case a new task is added. By combining only the AWA related tasks, it results in a utilisation of 154%, so around 77% per handler. In case AWA does all the packaging of R1 as well, it will result in a utilisation rate of 184%, which is a quite high for two handlers, but still doable.

Table 6-6: The utilisation rate of AWA table 17&20 in the current situation and solution 2. 181% is doable for two handlers, but also a bit high in case there is an increased workload.

Workstation AWA tables 17&20:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%
	+ AWA tasks from Robot 2	11:58:10	154%
	+ Stacking R2	12:31:19	162%
Solution 2:	+ Robot 1&2 packaging	14:02:23	181%

The Robot 2 handler only has to place and remove the products and remove the scrap, which results in a utilisation rate of only 28%. This is less than half a person and can therefore be done by the reparation person standing next to the robot, who also has half a day left.

Table 6-7: The utilisation rate of Robot 2 in the current situation and solution 2. The repair employee has tasks for half a day and can operate Robot 2, because 28% is also half a day.

Workstation Robot 2:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%
Solution 2:	Clamp, remove scrap, unclamp	02:08:57	28%

Robot 1 remains. Because the AWA with packaging has no time left, the robot handler has to stack the products himself, resulting in the earlier determined rate of 70%. Table 6-8 shows the overview of the old labour utilisation and the labour utilisation from solution 2.

Table 6-8: Solution 2, the overview of the new division of tasks, the old utilisation rate is compared with the new utilisation rate. Some of the tasks are moved from one workstation to another workstation. The repair employee has tasks for half a day and therefore can operate Robot 2 as well, because 28% is also half a day.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
	R2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
	Total:		**21:37:48**		**4**
Solution 2:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack from AWA tables 17,20 and R2+ packaging all stations	14:02:23	181%	2
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack	05:26:28	70%	1
	R2:	Clamp, remove scrap, unclamp	02:08:57	28%	0.5
	Total:		**21:37:48**		**3.5**

Figure 6.4 represents the combination of the new task division and handling equipment of solution 2.

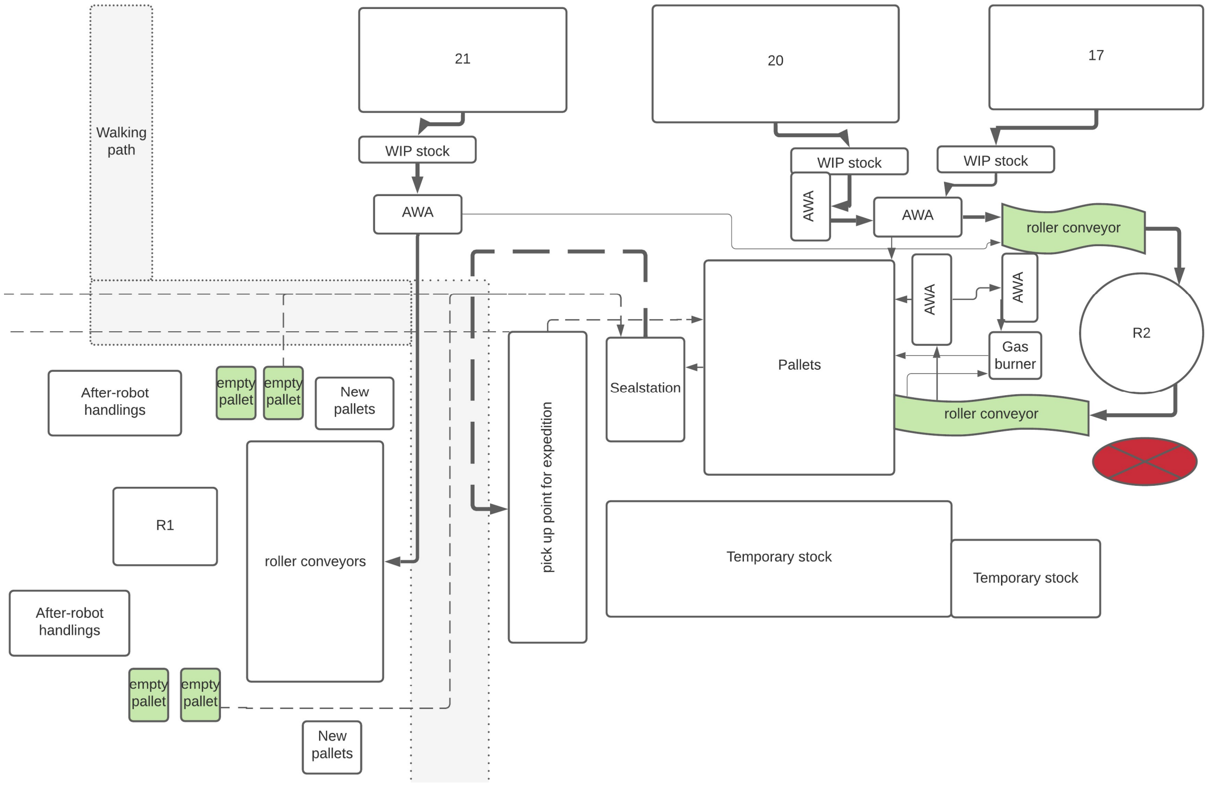

Figure 6.4: Solution 2 visualised. The Green parts are new, the Robot 1 handler stacks the products himself. The AWA tables and Robot 2 require two new roller conveyors.

6.3.4 Solution 3: moving all AWA tasks from R2 to AWA17&20 where R2 performs the packaging tasks

Solution 3 also combines all AWA table related tasks. The difference with solution 2 is that the packaging is now done by Robot 2 instead of the AWA tables. The steps in Table 6-9 show different utilisation rate at the AWA tables when removing or adding a task. 154% utilisation rate is too low for two handlers and 138% is too high for one and a half handlers. When adding conveyors, the AWA tables do not have to stack anymore, resulting in a utilisation of 125%, low enough for one and a half handlers.

Table 6-9: The utilisation rate of AWA table 17&20 in the current situation and solution 3. 125% utilisation rate requires one and a half handlers.

Workstation AWA tables 17&20:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%
	+ AWA tasks from Robot 2	11:58:10	154%
	No packaging	10:39:33	138%
Solution 3:	No stacking	09:41:58	125%

R2 does not have to perform AWA tasks anymore and has time left. Table 6-10 shows that adding the packaging and stacking activity to Robot 2 results in a utilisation rate of 87%, performed by only one handler.

Table 6-10: The utilisation rate of Robot 2 in the current situation and solution 3. The AWA table performs the AWA handlings required after the robot, so the product goes back to the AWA table.

Workstation Robot 2:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:
Current situation:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%
	Clamp, remove scrap, unclamp	02:08:57	28%
Solution 3:	Clamp, remove scrap, unclamp + all packaging & stacking	06:42:28	87%

The Robot 1 handler does not stack and package anymore, so his utilisation rate goes to the earlier established 67%.

Table 6-11 gives an overview of the task division, required time, utilisation rate and number of handers required with solution 3.

Table 6-11: Solution 3, the overview of the new division of tasks, the old utilisation rate is compared with the new utilisation rate. Some of the tasks are moved from one workstation to another workstation. Robot 2 performs the robot tasks and the packaging and stacking.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	R1:	Clamp, remove scrap, unclamp, clean,	07:30:40	97%	1
	R2:	Clamp, remove scrap, unclamp, clean,	04:54:58	63%	1
	Total:		**21:37:48**		**4**
Solution 3:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble and flame from AWA tables 17,20 and R2	09:41:58	125%	1.5
	R1:	Clamp, remove scrap, unclamp, clean and assemble	06:42:28	87%	1
	R2:	Clamp, remove scrap, unclamp + all packaging & stacking	05:13:22	67%	1
	Total:		**21:37:48**		**3.5**

Figure 6.5 visualises the combination of the solution 3 task allocation and the handling equipment. The recommendation is to have five extra conveyors.

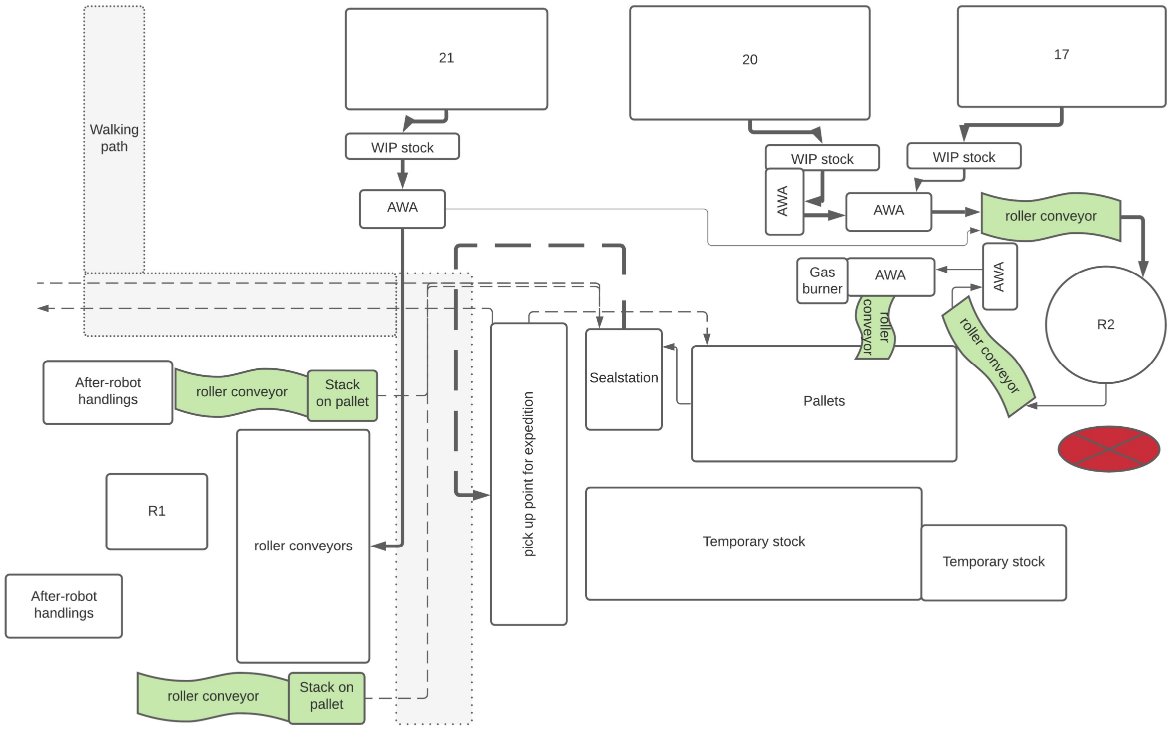

Figure 6.5: Solution 3 visualised. The Green parts are new, the Robot 2 handler operates the robot and stacks and packages the products of all workstations.

Table 6-12 displays the outcome of the different allocations of the tasks. The company board makes the choice for their optimal solution. All three solutions involve extra handling equipment, that improves the flow of the products, clarifies the task division and thereby saves half a handler.

Table 6-12: The overview of all solutions compared with the current situation.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
	R2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
	Packager:	-	-	-	-
	Total:		**21:37:48**		**4**
Solution 1:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean	06:47:13	88%	1
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack	05:26:28	70%	1
	R2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack + flame, assembly & stack from AWA 17&20	06:01:18	78%	1
	Packager:	All package	03:22:49	44%	0.5
	Total:		**21:37:48**		**3.5**
Solution 2:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack from AWA tables 17,20 and R2+ packaging all stations	14:02:23	181%	2
	R1:	Clamp, remove scrap, unclamp, clean, assemble, stack	05:26:28	70%	1
	R2:	Clamp, remove scrap, unclamp	02:08:57	28%	0.5
	Total:		**21:37:48**		**3.5**
Solution 3:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble and flame from AWA tables 17,20 and R2	09:41:58	125%	1.5
	R1:	Clamp, remove scrap, unclamp, clean and assemble	06:42:28	87%	1
	R2:	Clamp, remove scrap, unclamp + all packaging & stacking	05:13:22	67%	1
	Total:		**21:37:48**		**3.5**

6.4 Investment costs of the different solutions (SHA 8)

This section determines the investment costs of the observation suggestions and the costs of the required handling equipment for the different solutions.

6.4.1 The observation suggestions costs

The blue bins that still have wheels, have two swivel wheels underneath it. In production hall one, there are around five of those bins. In case all bins need two wheels, it requires ten wheels. The costs per wheel are maximal € 9,19 (Gamma, 2021). The investment is around € 90,-.

Next, buying one or two extra pallets carts decreases the waiting time for a pallet cart and the walking time and distance. Robot 1 has extra-long pallets that require an extra-long pallet cart. The price of an extra-long pallet cart will be around € 489,- (Corlido Group, 2021) and an extra normal pallet cart costs around € 225,- without tax (Corlido Group, 2021), resulting in the total investment being € 714,-.

The lowest price of the pallets made from EPS is € 3,75, but this depends on the purchasing number.

An extra garbage bin at the AWA tables starts from the price of € 27,25 euros without taxes (Manutan, 2021).

There are three methods for strapping a pallet, automatic, semi-automatic and manual. Figure 6.6 shows a fully automatic strapping machine. With an automatic strapping machine, the employee only needs to move the pallet twice, once for every strap. The price range for an automatic strapper is upon request (Transpak, 2021). It takes around 30 seconds per strap, so one minute in total for strapping one pallet.

Figure 6.6: A fully automatic strapping machine.

Figure 9.2 shows a semi-automatic strapping machine that can ride underneath the pallet, whereafter a handler only has to pick up the strap and bring it back to the machine, that pulls the strap tight and connect it. The price of the semi-automatic machine is around 3000 euros (Packer, 2021). The semi-automatic strapping machine takes around one minute before the pallet is strapped (Get packed, 2013).

Figure 6.7: A semi-automatic strapping machine.

With the automatic machine, the handler has to move the pallet itself. With the semi-automatic machine, the machine itself is moved, which is lighter and easier than the pallet. Because both machines take up equal times, the recommendation is to use the semi-automatic strapping machine, which is cheaper and easier to use. Table 6-13 displays the current average strapping times, the number of pallets that need strapping, the current total strapping time and the new total strapping with the use of the semi-automatic machine.

Table 6-13: the current strapping time per pallet times the amount of times strapping results in the current total strapping time. Having a strapping time of one minute with the semi-automatic strapping machine results in a saved time of almost an hour per shift.

Workstation:	Current avg strapping time: (hh:mm:ss)	Number of packaging (without boxes):	Current total strapping time: (hh:mm:ss)	New strapping time (semi-automatic): (hh:mm:ss)
AWA 17/20:	00:02:15	6.6	00:14:48	00:06:35
Robot 1:	00:03:18	17.9	00:59:00	00:17:51
Robot 2:	0:02:47	2.3	00:06:30	00:02:20
Total:			1:20:18	0:26:45

The decrease of the strapping time with the semi-automatic strapping machine is 67%, equal to almost one hour per shift.

The plate under Robot 2 will not need to carry a lot of weight. The surface area of the machine is:

$$\pi * diameter = \pi * 6 \approx 19\ m^2$$

The price of an lightweight metal sheet with the sizes of 1 m x 0,5 m x 0,75 mm is € 10,85 excluded taxes (Ijzershop, 2021). The total price will become € 409,04 euros. This investment will safe approximately 10 minutes of cleaning per shift at Robot 2.

The vacuum cleaner and air blower can be assembled on a swivel arm, that can be built upon the iron frame of the robot. It requires a slight adaption of adding a pole in the middle of the iron frame, before the arm can be assembled. The arm itself will cost around € 659,- (BEAM, 2021). The space that it saves is useful for walking paths and cooling stock storage. Appendix C provides more specifications.

Adding a strong PVC based canvas along the tables to make the cleaning easier costs around € 5,85 per m^2 (afdekzeilwinkel, 2021). Covering of the AWA tables at 17, 20 and 21 requires 20 m^2 of canvas, resulting in costs being € 117,- excluded taxes.

6.4.2 The costs of solution 1

The task division of solution one is as follows. One handler performs the tasks trimming, the quality check, drilling and cleaning the product at the combined workstation AWA tables 17 & 20. Robot 2 performs the tasks flaming and assembly, which is not required for every product. This results in requiring two conveyors, one from the AWA tables to Robot 2 and one directly to the packaging area. The advice is to have no conveyor between Robot 2 and the packaging area, because the Robot 2 handler stacks the products from himself and from the AWA tables. The handler at Robot 1 is stacking the products himself. One roller conveyor (l x b x h = 3 m x 0,56 m x 0,8 m) with legs will cost around 330 euros excluded taxes (material handling, 2020). Solution one requires two extra conveyors, resulting in € 660,- investment costs.

6.4.3 The costs of solution 2

Solution 2 uses the principle of combining all AWA and packaging related tasks to one island, where two handlers are working together. This requires the pallets to move backwards, so more space is available. Some of the products go to Robot 2 and come back, which requires two conveyors between AWA and Robot 2. Robot 1 performs the stacking task himself. This requires space for two extra pallets, one at each side of the robot. This solution requires two extra conveyors, resulting in € 660,- investment costs.

6.4.4 The costs of solution 3

The difference with solution 2 is that the packaging is now done by the Robot 2 handler. the products go from AWA to robot to AWA to packaging, or from AWA to packaging directly, this requires three extra conveyors. R1 will not stack and package the product himself and therefore requires two conveyors. In total, five conveyors with a total cost of 1600 euros is advised.

6.4.5 The costs overview

The observation suggestion that for sure has the most impact on the required working times, is the semi-automatic strapping machine, with a decrease of 67%, equal to almost one hour. The other observation suggestions are harder to estimate the impact, so for now, there is no change in those required working times. The change in packaging times influences the utilisation rates of the solutions.

Solution one has the packaging task done by a specific packager handler. With the strapping machine, it decreases from 44% to 32%, where 44% was close to the allowed rate for half a handler, the new utilisation rate of 32% is low enough to let him perform other tasks as well.

In solution two, the handlers at the AWA tables also perform the packaging task. Implementation of the semi-automatic strapping machine reduces the calculated utilisation from 181% to 170%, giving the handlers more time in case the machines produce products with more post-process work.

Solution two has the handler at Robot two performing the packaging task. The strapping machine decreases the labour utilisation rate from 87% to 67% . The lower one is preferable, because it provides more flexibility to have more products pass the robot.

Table 6-14 shows the differences of the labour utilisation between the solutions and the choice whether to implement the strapping machine or not. In all three solutions, it is recommended to buy the strapping machine, so the handler performing the packaging task does not have a schedule close to being too tight.

Table 6-14: The change in labour utilisation for the handler performing the packaging when implementing the strapping machine. The costs consist of the number of recommended conveyors and the choice whether to buy the strapping machine as well.

The solution:	Packaging task performed by:	Number of recommended conveyors:	Without strapping machine:		With strapping machine:	
			Costs: (€)	Labour utilisation:	Costs: (€)	Labour utilisation:
Solution 1:	Packager	2	660	44%	3660	32%
Solution 2:	AWA tables	2	660	181%	3660	170%
Solution 3:	Robot 2	5	1600	87%	4600	67%

6.5 The chosen solution (SHA 9)

The choice for the solution is in consultation with the company and depends on some criteria. The time it requires for finishing one products depends on its type. This may result in having a combination of products on the rotational machines that require a high or low workload. Next to that, adaptation options is of interest for the longer view, in case of the introduction of new products. One of the goals of Promens is to have a high robot utilisation. Next, the costs of the investment should not be too high compared to get the desired outcome. At Robot 1, it is proven that visualisation of the amount of work, for example with the use of roller conveyors, guides the personnel in choosing the order of their tasks and therefore is included in the judgement for choosing a solution. Table 6-15 visualises the judgement, given by the innovation manager and the production manager, for each of these criteria at the different solutions by using a one to five scale, one being less desirable and five being good. The company prefers the decrease of the required strapping time. Therefore, all proposed solutions involve the strapping machine.

Table 6-15: The judgement of the solutions, based on the given criteria, in consultation with the company.

	Flexibility adaptation on workload:	Adaptation options:	Improved robot utilisation:	Costs:	Visualisation for the handlers:	Monitoring quality:	Sum of the points:
Solution 1:	1	1	4	4	3	2	15
Solution 2:	4	3	4	4	3	4	22
Solution 3:	4	3	2	3	5	4	21

Solution one has only one employee at the AWA workstation and is therefore volatile for a too high workload. The AWA table tasks are decentralized, making it less flexible and harder to monitor the quality of the products. However the costs are low and by only adding two extra conveyors, implementation is easier.

Solution two uses two roller conveyors visualising the workload and flow of the products. The utilisation from Robot 2 has upscale options, because the handler has work for less than half a day. The products start and end at the same station, making it easier to monitor the quality. The visualisation for the handlers is on average, because the person packaging cannot see easily when a pallet from Robot 1 is full.

Solution three involves having two conveyors at Robot 1, easily visualising the amount of finished products for the handler performing the packaging. The workstation AWA table can monitor the products from beginning till end. There is less flexibility for an improved robot utilisation at Robot 2, because the handler also performs the packaging.

The implementation of two extra conveyors at Robot 1 has their preference, together with the division of tasks at solution two, having the AWA tables performing the packaging. This combination is possible, but only with the implementation of the strapping machine. Table 6-16 provides the new division of tasks and utilisation rates. Figure 6.8 visualises this new combined solution. The solution requires four roller conveyors and the strapping machine, resulting in investment costs of € 1270,- euros.

Table 6-16: Solution 2 & 3 combined together with the current situation. The combination is only possible with the use of the semi-automatic strapping machine. The Robot 2 handler has time to perform the reparation tasks as well, which is next to his own workstation.

	Workstation overview:	The tasks:	The required time: (hh:mm:ss)	Utilisation rate:	Number of handlers:
Current situation:	AWA tables 1	Trim, quality check, drill holes, bring to cooling, clean, assemble, flame, stack, package	09:12:10	119%	2
	Robot 1:	Clamp, remove scrap, unclamp, clean, assemble, stack, package	07:30:40	97%	1
	Robot 2:	Clamp, remove scrap, unclamp, clean, assemble, flame, stack, package	04:54:58	63%	1
	Total:		**21:37:48**		**4**
Solution 2 & 3 combined:	AWA 17/20	Trim, quality check, drill holes, bring to cooling, clean, assemble and flame from AWA tables 17,20 and R2 + stack & package all stations	13:21:40	172%	2
	R1:	Clamp, remove scrap, unclamp, clean and assemble	05:13:22	67%	1
	R2:	Clamp, remove scrap and unclamp	02:08:57	28%	0.5
	Total:		**20:44:00**		**3.5**

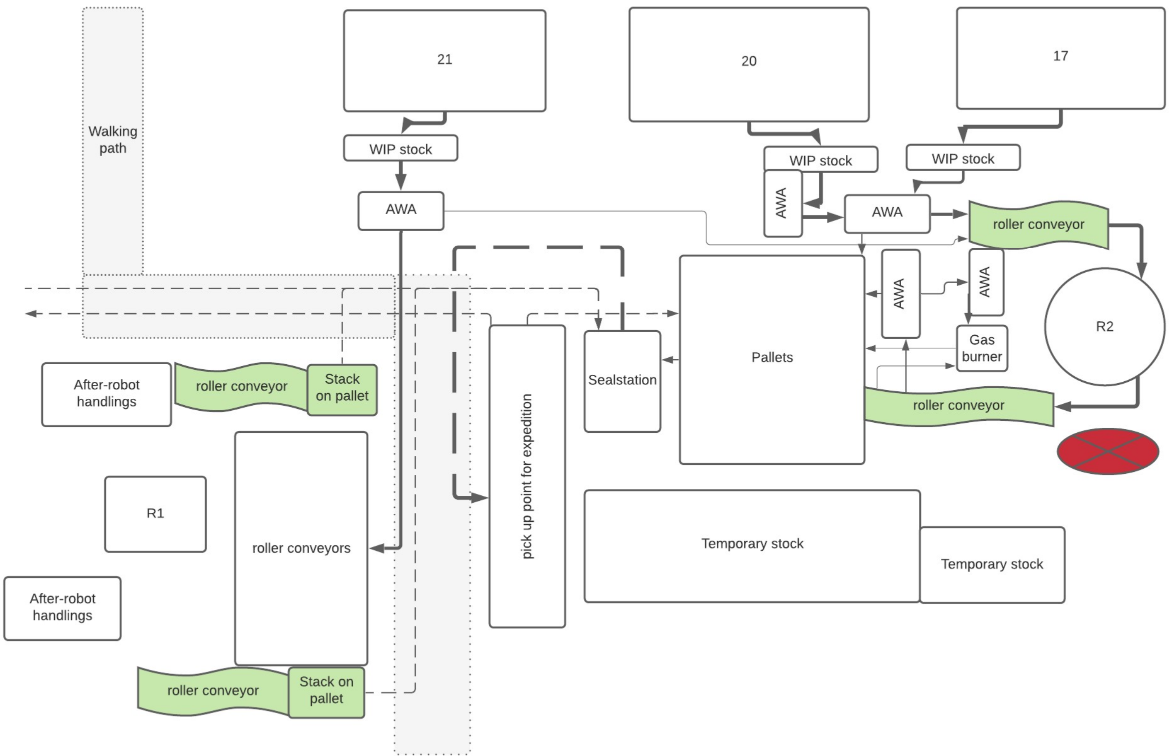

Figure 6.8: The green parts at Robot 1 come from solution 3, while the setup at the AWA tables and Robot 2 is from solution 2. The combination has the preference of the company, but is only possible with a semi-automatic strapping machine. AWA 17 & 20 perform the packaging of the other stations as well. The products pass the AWA tables at the beginning and in the end to assure the quality of the products.

6.6 The implementation plan

Most of the observation suggestions are easier to implement rather than reallocating the tasks between the stations. Therefore, the recommendation is to first implement the observation suggestions that are most useful, because they do not require big adaption from the handlers and only make the tasks easier.

Properly explaining the new division of tasks and their role in it is of the greatest importance. This shall not be rushed. The implementation requires in-between checks whether they are performing it right. The handlers are allowed to help each other, but only in case it is really necessary and does not affect their own tasks. The KPIs on the dashboard provide information to track the results of the implementation, so the production board can intervene if necessary. Table 6-17 provides an overview of the recommended order of implementing the observation solutions, selecting on the level of difficulty of improvement.

Table 6-17: The stepwise approach of the implementation of the observation suggestions, rated from easy to implement until hard to implement.

		Type of improvement:	Workstation:	The improvement:
Observation suggestions:	Easy:	Ergonomics	Both Robots	Add wheels below the blue bins
		Ergonomics	Robot 1	Buy one extra long pallet cart
		Handling effort	AWA table 17&20	Buy one extra trash bin
		Handling effort	All	Buy at least one extra normal pallet cart
	Middle:	Safety	AWA table 17	Replace the feet pedals with buttons next to the table
		Handling effort	All	Add the work instructions in the computer
		Handling effort	Packaging	Buy a semi-automatic strapping machine
		Decrease cleaning time	AWA tables 17&20	Close the open sides of the AWA tables with curtains or plates
	Hard:	Ergonomics	Packaging	Use lighter pallets made from reusable plastic
		Handling effort	All	More consequence when registering finished products
		Decrease cleaning time	Robot 2	Add a flat bottom to to catch the scrap
		More walking / storage space	Robot 2	Move the cleaning equipment from the three poles to one swivel arm on top

Table 6-18 suggests the stepwise approach for implementing the new allocation of tasks and the handling equipment. This requires time, so the handlers can adapt to the new situation.

Table 6-18: The stepwise approach for implementation of the new division of tasks and handling equipment.

	Implementation order:	The implementation activity:
The solution, a combination of solution 2 & 3:	1	Explain <u>only</u> the function of the roller conveyors at Robot 1, visualising the finished products
	2	Two new conveyors at Robot 1 and letting AWA perform the packaging
		Wait at least two weeks
	3	Check the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate
	4	Evaluate the implemented roller conveyors.
	5	Explain <u>only</u> the function of the roller conveyor between Robot 2 and the packaging, removing the packaging task and adding it to the AWA tables
	6	Implement the roller conveyor between Robot 2 and the packaging workstation
		Wait again at least two weeks
	7	Check again the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate
	8	Evaluate the implemented roller conveyors
	9	Explain the <u>complete</u> final task division and make sure they are not helping each other too often
	10	Implement the roller conveyor between the AWA tables and Robot 2
		Wait at least two weeks
	11	Big evaluation: Check the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate

7 Conclusions and recommendations

This chapter first summarizes the chapters and thereby answers the main research question. The recommendations involve the recommended solution, the discussion and suggestions for further research.

7.1 Conclusions

Promens requested several options to improve their labour utilisation of the handlers performing the post-process activities of their products made by rotational moulding. Therefore, the research question answered is:

> *"What improvements can be made in the production process of Promens in order to improve the labour utilisation of the employees?"*

The theoretical frameworks involved in this research are the Systematic Handling Analysis and the lean principle, together with the production steps required for producing products with rotational moulding. These formed the guide for providing a clear overview of the different tasks and the route the product follows through the production hall. The current process is based on the lean principle of having a one-piece flow process to ensure the quality of the products and thereby have a low rejection rate. There are four stations present in the production process, the rotational moulding machines, the handlers, the robots and the packaging. The handling activities for the last three stations are determined and measured in time, resulting in the required time per activity for every station during one shift. Table 7-1 shows the current labour utilisation determined for each station.

Table 7-1: The current labour utilisation ratios at each station.

AWA table 17:	57.7%
AWA table 20:	65.8%
Robot 1:	93.9%
Robot 2:	68.7%

The combination of the utilisation ratios and the required time per activity per workstation makes it possible to develop new solutions involving reallocating the activities. This requires that the handling methods between the stations must be altered to implement the chosen solution.

It turns out that the employees are walking a lot, which is not a value adding activity. The theoretical question 'What methods are accessible to decrease the walking distances in a production process?' provides several methods that are kept in mind while forming the solutions, such as not letting workers cross paths and having component racks not being too large, too long or have too many products on it. Promens uses a linear production layout in the current situation, but a U-, L-, or two-sided shape is recommended, because they increase the visibility and communication.

Next to that, mathematical models such as the MILP, the CP or the MONDEN help with the allocation problem of the employees. MILP gives opportunities to move the tasks around, while CP and MONDEN provide constraints that need to be kept in mind.

Depending on the product type and intensity of flow, the SHA suggests a different type of handling equipment. Promens does not have a high variation between products. The distances between the workstations are mediate, but the intensity is high. The recommendation is to use a direct system with complex handling equipment. Promens has a fixed path between the workstations and therefore a conveyor belt fits best. There are different types of conveyor belts, because the products move horizontally and the flow is irregularly, a gravity-roller or wheel conveyor is recommended. With the product types of Promens, both conveyors are accepted.

Limitations in changing the handling methods and division of tasks are the safety of the personnel and reachable by hand. The hall should remain clean, so the scrap can be recycled. The are no limitations on the area, because the hall is not fully used. The ceiling is full and therefore no handling methods can be attached there.

The proposed solutions to improve the labour utilisation are based on two thoughts: removing tasks until only one handler at AWA tables 17&20 is required, or combining all AWA tasks into one spot. Within the second thought, a difference is made between the choice for which handlers are performing the packaging, done by the AWA tables as well or the Robot 2 handler. All three solutions require different set-up of handling equipment, depending on the new task division. Suggestions for easing the workload of the employees are making it easier to clean by shielding the harder to reach spots. Buying extra pallet carts will decrease the walking distances, and when buying a semi-automatic strapping machine, the packaging time decreases with 67%, equal to almost one hour.

7.2 Recommendation to the company

The recommendation for Promens is to make use of a combination of the proposed solutions. In all three solutions, the strapping machine makes a significant impact on whether the employee has a tight schedule or a bit more time. The strapping machine allows a task division which is a combination of solution two and three. Two handlers on a central AWA table island will perform all the AWA related tasks and the packaging tasks. The Robot 2 handler will only clamp, remove the scrap and unclamp the products from the robot, taking up half a shift. The advice is to add two extra roller conveyors at Robot 1, where the handler can place his finished products, visualising the amount of finished products for the packaging department. Four conveyors in combination and one strapping machine results in total costs of € 4270,-. Table 7-2 and Table 7-3 show the recommended order for implementing the observation suggestions and the new division of tasks.

Table 7-2: The stepwise approach of the implementation of the observation suggestions, rated from easy to implement until hard to implement.

		Type of improvement:	Workstation:	The improvement:
Observation suggestions:	Easy:	Ergonomics	Both Robots	Add wheels below the blue bins
		Ergonomics	Robot 1	Buy one extra long pallet cart
		Handling effort	AWA table 17&20	Buy one extra trash bin
		Handling effort	All	Buy at least one extra normal pallet cart
	Middle:	Safety	AWA table 17	Replace the feet pedals with buttons next to the table
		Handling effort	All	Add the work instructions in the computer
		Handling effort	Packaging	Buy a semi-automatic strapping machine
		Decrease cleaning time	AWA tables 17&20	Close the open sides of the AWA tables with curtains or plates
	Hard:	Ergonomics	Packaging	Use lighter pallets made from reusable plastic
		Handling effort	All	More consequence when registering finished products
		Decrease cleaning time	Robot 2	Add a flat bottom to to catch the scrap
		More walking / storage space	Robot 2	Move the cleaning equipment from the three poles to one swivel arm on top

Table 7-3: The recommended stepwise approach for implementation of the new division of tasks and handling equipment.

	Implementation order:	The implementation activity:
The solution, a combination of solution 2 & 3:	1	Explain only the function of the roller conveyors at Robot 1, visualising the finished products
	2	Two new conveyors at Robot 1 and letting AWA perform the packaging
		Wait at least two weeks
	3	Check the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate
	4	Evaluate the implemented roller conveyors.
	5	Explain only the function of the roller conveyor between Robot 2 and the packaging, removing the packaging task and adding it to the AWA tables
	6	Implement the roller conveyor between Robot 2 and the packaging workstation
		Wait again at least two weeks
	7	Check again the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate
	8	Evaluate the implemented roller conveyors
	9	Explain the complete final task division and make sure they are not helping each other too often
	10	Implement the roller conveyor between the AWA tables and Robot 2
		Wait at least two weeks
	11	Big evaluation: Check the KPIs at the dashboard and measure the robot utilisation rate and AWA labour utilisation rate

7.3 Contribution to theory and practice

This section summarizes the contribution of this research to the theory and practice.

7.3.1 Contribution to theory

Within this research, the SHA is applied from the lean perspective, eliminating waste such as walking. The research proves that the SHA can be applied on smaller parts of the factory, instead of only on factories as a whole. It turns out that the combination of reallocating the tasks with implementation of new handling equipment can be done best by first gathering information of the tasks, whereafter a new division of tasks is made and the handling equipment is chosen last, depending on the products and the flow between the workstations. The combination of existing methods is applied to a smaller part of a big factory, all with the goal to make better use of the employees.

7.3.2 Contribution to practice

The research mainly focused on being of value for the company. Improving the labour utilisation saves half an employee and divides the workload more equally, increasing the satisfaction between the employees. The report functions as a guide for the implementation of the combination of the theoretical framework, the SHA, the lean principle and the rotational moulding production process. With the use of a production dashboard, the implementation of the developed solution is taken into account, making sure that the production level and quality will not decrease.

7.4 Discussion

The foremost limitation is the ten weeks given for this research. The developed solution will not be implemented during the research itself and the results will therefore not be proven in reality.

For developing the solution, a general view of the required time of the activities is gathered. This is done in three weeks of measurements. During these measurements, the attempt is made to measure both shifts an equal amount. The measurements were only done when there was no inconsistency in the production, there were no extra tasks and no backlog stock was present. Nevertheless, small differences during measurements, such as employees quality, different product combinations or way of working were not taken into account and might have a small influence on the outcome.

The measurements were done by hand and rounded to five seconds accurate. Two types of validations are performed. First, A validation to see whether the total measurement time was equal to the total time that should be measured. Second, averages are taken regarding the input variables, such as the amount of products on the rotational moulding machines and the number of products on one pallet. When using this for calculating the required time per activity for every workstation in one shift, it is important to check whether the averages are valid, by comparing the outcome with the earlier calculated utilisation rate and the total hours that the employees perform that activity. The first validation check had a deviation of less than 1%, making it reliable. The second validation check shows small differences, which are acceptable for the company. Nevertheless, it must be noted that the averages and rounding errors have influence on the outcome.

Another limitation in this research is the knowledge of myself regarding factory processing equipment. By visiting companies and searching on the internet, multiple ideas came forward. But for me as a student, it is not possible to know all the existing machines available for a production process.

The existing data regarding the KPI performance is from the past half year. Due to covid-19, their illness numbers are a bit different than normal, but by measuring on times where no employees were sick, this problem was tackled. However, this might have a small influence on their KPI numbers over the past half year. The company still gave me the opportunity to walk through the production hall and talk with the employees, so the covid limitations did not cause a remarkable limitation during the research.

When implementing a solution, the employees are the most reliable factor. They need to understand the advantages and have to accept the new situation, so the motivation of working remains. Besides that, the employees need to be trained thoroughly for correctly executing the solution. Motivation of the employees to stand up and introduce better ideas is required as well in case in reality smaller issues arise that need solutions.

7.5 Further research

A suggestion for further research is to extend the current solution to rotational moulding machine 14 and 16 and combine them with AWA tables 17&20, Robot 1 and Robot 2. By executing the same stepwise approach done during this research, a clear concept of the type of products and the movement possibilities are visible.

Next, the SHA can also be executed throughout the whole factory, mapping all the different routes, the frequency at those routes and the types of material.

This research mainly focused on optimizing the labour utilisation by reassigning the tasks and the implementation of handling equipment. A next step can be to perform research on the layout of the hall. For now, this is not drastically changed, but by redesigning the layout, optimal routes can be established. A method for redesigning the production facility, is the Systematic Layout Planning (SLP).

For further research, gathering more detailed times, such as the time per activity per product, can help with scheduling the right amount of workers throughout the different product types combinations, that differ every week.

In the current situation, the production schedule is made without taking into account the workload of the employees performing the tasks and only the limited space on the machine is considered. By combining these two variables, together with the other variables determining the production line, an optimal balance can be found. Before this can be the new situation, research is required.

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Appendix

A. Production plant Layout

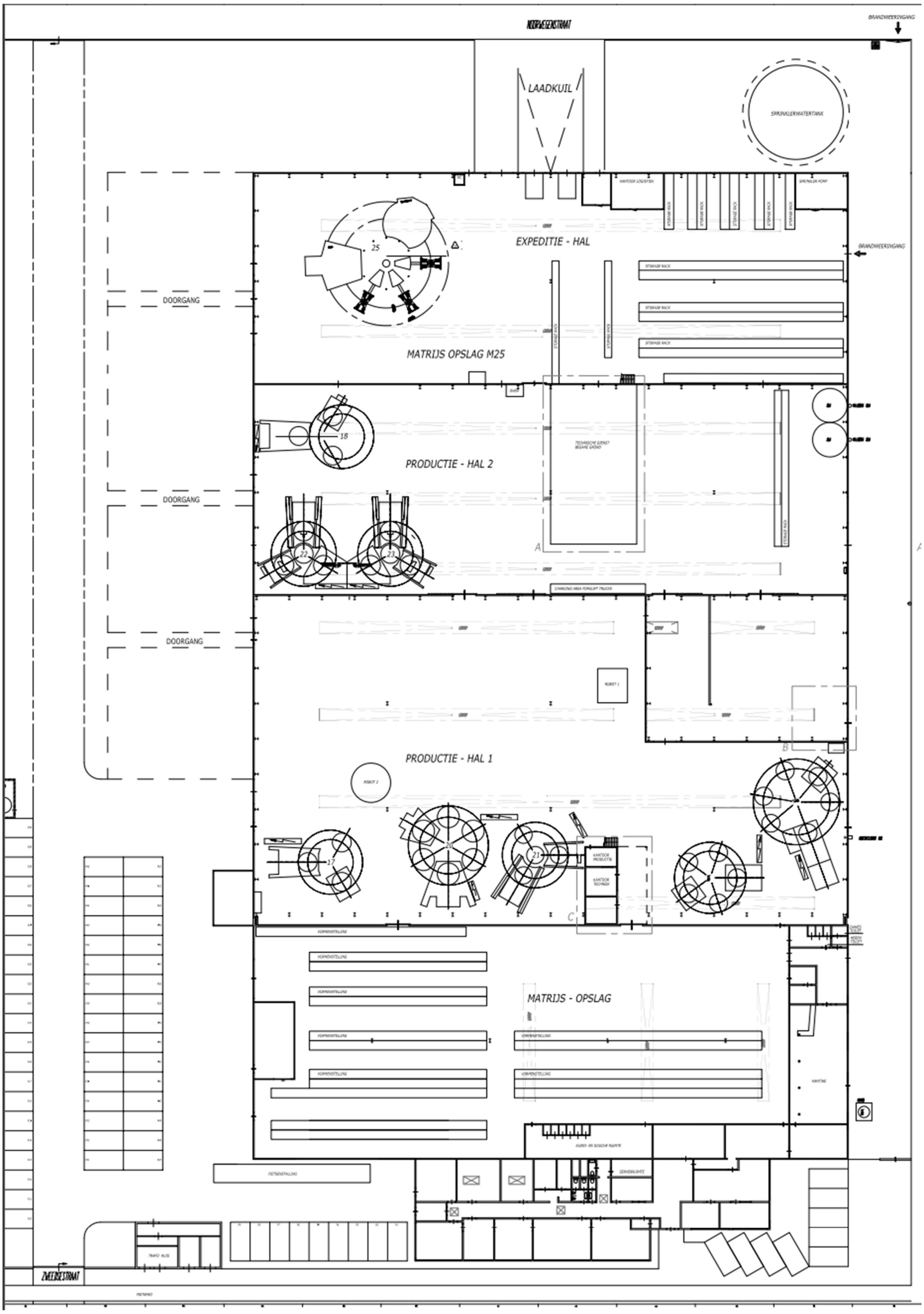

Figure A. 1: The production facility with the different halls. Hall one is the one with the five machines, where the research took place.

B. Measurement sheet

i. The AWA tasks

Table B- 1: The tasks performed at one of the AWA tables next to machine 17, 20, 21, Robot 1 or Robot 2.

mm:ss

Date: Time slot:

AWA 14 / 16 / 17 / 20 / 21

product type	trim edges	quality check, what does employee and how long?		drill holes	clean product	assemble parts	bring to robot	bring to pallet	gas burner	waiting times

i. The robot tasks

Table B- 2: The tasks performed at Robot 1 or Robot 2.

mm:ss

Date: Time slot:

Robot 1 / 2

product type	clamp product	robot drills, what does employee and how long?		remove scrap	unclamp	waiting times

ii. The packaging tasks

Table B- 3: The performed tasks done by the handlers before the pallet is ready to get picked up by expedition.

mm:ss

Date: Time slot:
Packaging 14 / 16 / 17 / 20 / R1 / R2

product type	grab cart	bandoling	seal by hand	plastic bag	robot seals, what does employee and how long?		expedition	new pallet	carton box	waiting times

C. Different types of conveyors

Chute conveyor

(Indiamart, 2021)

Powered-roller conveyor

(Neetwk, 2021)

Slat conveyor

(Shmula, 2014)

Belt conveyor

(Indiamart, 2021)

Gravity-roller conveyor

(material handling, 2020)

Wheel conveyor

(yfconveyor, 2021)

Swivel arm with vacuum cleaner

(Kemper, 2021)

Swivel arm with haspel

Specifications: 3 meters long,€ 659,- ex btw, 270 degrees turning.

(stofzuigers, 2021)

D. D3: Do, Discover, Decide

Do: list all activities that need to be performed.
Discover: search for everything you need to know and understand.
Decide: select the proper options, define the research scope.
(Heerkens, 2018).

E. Managerial Problem-Solving Method (MPSM)

The MPSM consists of seven phases, all required to get with a structural way to a solution for a business problem (Heerkens, 2018).

1. Defining the problem.
2. Formulating the problem.
3. Analysing the problem.
4. Formulating (alternative) solutions.
5. Choosing a solution.
6. Implementing the solution.
7. Evaluating the solution.

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