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Improving the production rate and decreasing the variation of the delivery times of Instalsolutions

BSc Industrial Engineering & Management

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Improving the production rate and decreasing the variation within the delivery times of Instalsolutions

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Preface

Dear reader,

You are about to read the results of my bachelor's graduation thesis in the field of Industrial Engineering and Management, at the University of Twente. I conducted research for HoSt Bioenergy Systems in the period from February 2022 to August 2022. HoSt Bioenergy Systems has a majority stake in Instalsolutions, a manufacturing and assembling company located in Poland. In my research, I determine how Instalsolution can increase the production rate and decrease the variation of the production times of the sub-assemblies and final products. This is done by gathering data via in-depth interviews with the employees of Instalsolutions. With this data a new working structure was set up, a simulation was made to find the bottlenecks within the production process and new warehouse layouts have been provided.

I want to thank my supervisor Raymond Enkt from HoSt Bioenergy Systems and Martyna Roszak from Instalsolutions. They both guided me during the research and always helped me when needed. Furthermore, I could always count on their extensive feedback. I enjoyed working with them. During my research, I was able to pay a visit to Instalsolutions and had the opportunity to ask questions regarding the production facility of Instalsolutions. Therefore, I want to thank all employees who helped me gather insights into the production process and data for my research.

I would also like to thank Dennis Prak, my first supervisor from the University of Twente. He provided me with extensive and clear feedback, which strongly enhanced the quality of my report. Dennis' large enthusiasm and interest supported me throughout the entire process. I would also like to thank Patricia Rogetzer my second supervisor from the University of Twente.

Lastly, I would like to thank my family and friends for their support, interest, and feedback.

Maarten Zwiers, 2-8-2022, Enschede

Management summary

Introduction

HoSt Bioenergy Systems is a global corporation with over 250 employees, whose activities focus on the technological development of waste-to-energy systems for processing biomass and waste flows and the supply of systems for sustainable energy generation from biomass and waste. This research is conducted at Instalsolutions, a manufacturing and assembling company of HoSt Bioenergy Systems.

Motivation and core question of this research

In this thesis, we investigated how Instalsolutions can increase the production rate and decrease the variability of the throughput times of sub-assemblies and final products. This is important since there is more demand than the company can supply, leading to a lack of production capacity. For this reason, the following research question was set up.

"How should Instalsolutions increase the production rate and decrease the variability of the throughput times of sub-assemblies and final products?"

The research is split up into three sub-questions to answer this broad research question. The three sub-topics are represented in the sections of Chapter 2, Chapter 3, Chapter 4, Chapter 5 and the sub-sections of Chapter 6.

1. *"How can Instalsolutions decrease variability of the throughput times of sub-assemblies and final products by creating a clear working structure?"*

We have set up a working structure for Instalsolutions. This was necessary to decrease the variation within the production line and create more structure within the production process of Instalsolutions in general.

2. *"Can the production rate of Instalsolutions increase by optimizing the production process?*

We created a simulation model which helped to locate the bottlenecks within the current production process. Once the bottlenecks are identified Instalsolutions can investigate solutions to relieve the bottlenecks and create a smooth production flow.

3. *"How should Instalsolutions rearrange the warehouse to optimize the storage space within the current plant?"*

We will investigate how Instalsolutions can rearrange the warehouse layout to optimize the available storage space. This is necessary since all products will be directly delivered to Instalsolutions and sub-assemblies will be made on stock to increase the production rate. To store all buy-in products and the sub-assemblies make-to-stock (MTS) more space within the warehouse must be created.

Problem-solving approach

First, the current production process of Instalsolutions is analysed. This analysis concerns the following information:

1. The current working structure of Instalsolutions
2. The current production process of Instalsolutions
3. The current warehouse layout of Instalsolutions.

Secondly, the problem-solving approach is based on the literature on the three sub-topics mentioned above. First, we gather knowledge on how to create a standardized working structure, this is done by investigating the 5S management theories. Second, we investigate possible optimization steps within the production process of Instalsolutions. More specifically, we investigate the possibilities of starting partial make-to-stock production to decrease the variation and minimize the idle time within the production process. We will refer to the partial make-to-stock production strategy as delayed product differentiation. Lastly, a systematic literature review is performed on which safety rules must be met within a warehouse and we investigate how the storage space within a warehouse can be optimized.

Thirdly, the solution design is set up. In the solution design, we apply the gained knowledge from the literature research to the situation of Instalsolutions. We first discuss the benefits of the 5S management technique, how we will take this into account when we set up the working structure and how it can be implemented at instalsolutions. Furthermore, we explain how the working structure will help to gather necessary data. We explain how we created a simulation model which represents the current production process of Instalsolutions and how the model will be adapted to a delayed differentiation production process. We explain how the safety rules and space optimization will be applied within the warehouse of Instalsolutions. Lastly, the influence of variability within the production process of Instalsolutions is discussed.

Results, conclusion, and recommendation

Fourthly, the results of the research are presented. We created a step-by-step working structure for Instalsolutions which will improve the quality of the products. Furthermore, the working structure will help instalsolutions to have a clear overview of the production process and to keep the workspace clean. The time spent on seeking necessary things will reduce and the safety level will increase. Furthermore, industrial pollution will decrease, employee motivation will increase, and more structure is provided to help gather the necessary data.

Within the second deliverable, we provided instalsolutions with an overview of how to distribute the workforce to create the most optimal workflow within the production process of Instalsolutions. Based on this optimal workflow the idle times per station and the throughput rate of the production process are given. We have found the bottleneck within the production process is found.

The last deliverable provides instalsolutions multiple solutions to generate more storage space within the warehouse. We recommend different warehouse solutions based on the current forklift trucks available and when a reach truck is bought by Instalsolutions. Instalsolutions can choose which warehouse layout to implement once the data is gathered to decide the total storage space needed. This is done since on short notice all products will be directly delivered to Instalsolutions, and sub-assemblies will be made on stock to increase the production rate. To be able to store all buy-in products and the sub-assemblies make-to-stock (MTS) more space within the warehouse must be created. Overall, we created insights and understanding in the production process of Instalsolutions and made visible which data must be collected.

We recommend Instalsolutions to implement the new working structure, as described in the first deliverable, implementing the 5S management strategy, will create a structured and fluent production process which helps Instalsolutions n process which helps Instalsolutions to gather the necessary data. Once the data is gathered another research could be conducted to create a more specified simulation model on the production process of Instalsolutions and design a product-specific warehouse layout.

Contents

Reader's guideline

In this reader's guide, a short and clear overview is given of what can be found in which chapter of this research. This will help when searching for information regarding a specific topic. In the case of reading the whole thesis, the guide gives an idea of the direction in which the research is going.

Chapter 1 Introduction

This chapter introduces the research that is conducted within this bachelor thesis. Section 1.1 consist of an introduction to the company and the department in which the research is conducted. In Section 1.2 the research motivation is mentioned, and the goal of the research is stated. The context and the deliverables of this thesis are stated in Section 1.3.

Chapter 2 The starting point of Instalsolutions when the research was conducted.

In this chapter, the starting point of the research is described. In Section 2.1 we investigate if there are any benefits to be made to the current working structure of Instalsolutions. Section 2.2 displays the current production process of Instalsolutions. We look at the way the warehouse racks are placed inside the warehouse and how the warehouse space is used at Instalsolutions in Section 2.3.

Chapter 3 Background study on working structures, optimizing production processes, and optimizing a warehouse.

Before coming up with a solution, a theoretical perspective is created which will be discussed in this chapter. In Section 3.1 a literature review is performed on how to create an efficient working structure, this is based on the 5S management technique. A systematic literature review regarding delayed product differentiation and minimizing idle time within the production process is performed in Section 3.2. Lastly, Section 3.3 states what must be taken into consideration when designing a warehouse layout.

Chapter 4 Solution design

In this chapter, we start working towards the solutions of our research. In Section 4.1 the theory gained in Section 3.1 is applied to Instalsolutions and the benefits of the work structure are addressed. In Section 4.2 the production process is rearranged, and how this will be represented by the simulation model is discussed. The safety rules and ways of optimization applied to Instalsolutions are mentioned in Section 4.3. Lastly, Section 4.4 explains the data used in the simulation model and the settings of the simulation based on the available data are discussed.

Chapter 5 Results

In this chapter, the results of our deliverables will be discussed. In Section 5.1 the new working structure created is presented. In Section 5.2 the outcome of the simulation model is discussed. Lastly, the new warehouse layouts and results of the warehouse layouts are discussed in Section 5.3.

Chapter 6 Conclusions, recommendations, discussion and future research

This chapter covers the conclusions, recommendations, and a discussion on the assumptions and limitations of this research. Furthermore, future research which can be conducted at Instalsolutions is mentioned.

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List of abbreviations

ERP	Enterprise Resource Planning
MTS	Make To Stock
MTO	Make To Order
TQM	Total Quality Management
WIP	Work In Progress

1. Introduction

This chapter introduces the research that is conducted within this bachelor thesis. Section 1.1 consist of an introduction to the company and the department in which the research is conducted. In Section 1.2 the research motivation is mentioned, and the goal of the research is stated. The context and the deliverables of this thesis are stated in Section 1.3. Section 1.4 consist of a brief outline of what is discussed in the remainder of this thesis.

1.1 Company description

HoSt bioenergy systems is a family company that came into existence in 1991 as the result of a joint venture between Holec Projects and Stork, two well-established suppliers of energy systems. From 1999 onwards HoSt has been a fully independent business whose activities focus on the technological development of waste-to-energy systems for the processing of biomass and waste flows and the supply of systems for the sustainable generation of energy from biomass and waste. HoSt bioenergy systems have built up extensive experience in the processing of diverse waste flows from the food-processing industry and agricultural by-products. HoSt bioenergy systems have grown into a global organization with an annual turnover around 70 million euros, an employee count exceed 250 people, a large service team throughout Europe, multiple offices in both the US and Europe, a large network of sales representatives and partner distributors, and bioenergy projects all over the world. The vision of HoSt bioenergy plants contributes to ensuring the success of a circular economy by producing renewable energy, solving waste management challenges, and creating valuable end-products from organic waste. (HoSt Holding B.V., 2021)

In August 2017 HoSt bioenergy systems launched Bright Biomethane, this is a new subsidiary dedicated to biogas upgrading in a bid to focus on the rapidly growing biomethane market sector. Bright Biomethane offers well-proven systems with a membrane technology to upgrade biogas to biomethane, an example of such a system can be found in Figure 1. These biogas upgrading systems are made by Instalsolutions in Poland. In March 2021 HoSt bioenergy systems acquired a majority stake in Instalsolutions in Poland. Instalsolutions is a manufacturing and assembling company specialized in industrial piping installations, containers, and modular structures. Instalsolutions is a quickly growing company that currently has 45 to 50 employees.

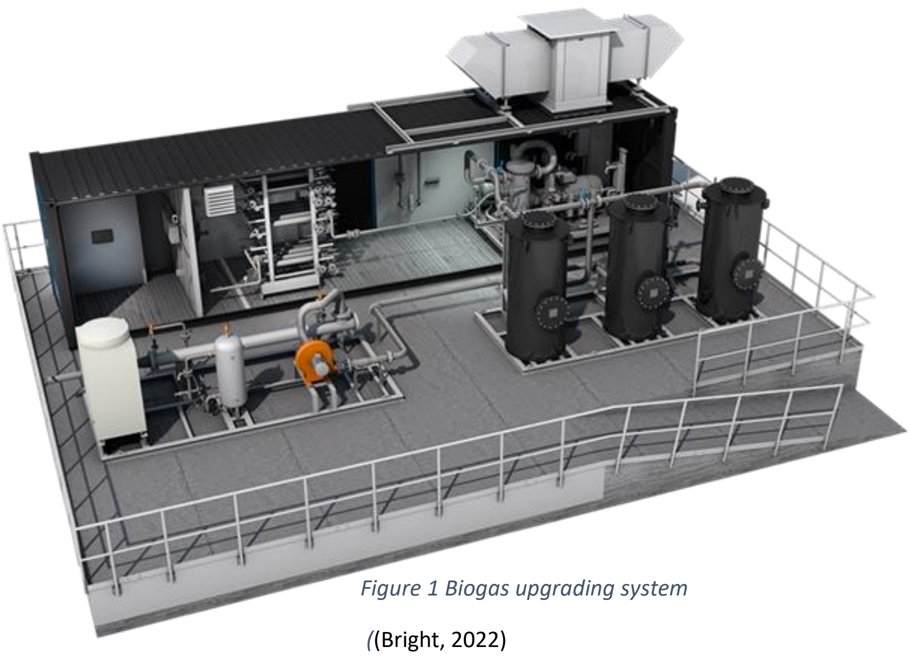


Figure 1 Biogas upgrading system

((Bright, 2022)

1.2 Research motivation

HoSt bioenergy systems is a fast-growing company and there is more demand than the company can supply. The company cannot supply all products due to a lack of production capacity. All production was done by external companies. To increase the production capacity HoSt bioenergy systems became a majority stakeholder of one of the production companies, Instalsolutions in March 2021. This bachelor thesis is conducted at Instalsolutions, a manufacturing and assembling company. Instalsolutions is mainly focused on producing the biogas upgrading systems of HoSt bioenergy systems, hence only this product will be taken into consideration during this bachelor thesis. The biogas upgrading system is a product as shown in Figure 1, which is suitable for all types of new and existing biogas plants in any industry, and suitable for biogas produced from any form of organic waste, including municipal sludges and wastes. The main customers of HoSt bioenergy systems are other businesses. Since HoSt bioenergy systems bought a majority stake in Instalsolutions the company is growing rapidly. This results in more people getting hired but the company structure cannot keep up with the rapid growth of the company, this led to an increase in the variability of the delivery times of the final products. The result of this is being late to deliver the final products to the end customers. To understand the consequences of being late, it is important to first understand that projects are not subsidized by governments, but the customers of HoSt bioenergy systems will get a fixed amount of money for the biogas the customers deliver for a fixed number of years. This amount of money depends on the timeslot in which the first biogas is injected into the natural gas grid. So, when the bioenergy upgrading system is not delivered on time this can have a lot of consequences for the customers. Because they cannot deliver the first biogas to the natural gas grid within the agreed-on timeslot. Delay in production hurts the company's relationship with the customer and the company needs to get a team to the bioenergy upgrading system to assemble the last products on site, which costs the company money. Hence it is of great importance that next to the increased production capacity the products are delivered within the agreed time frame.

This problem is translated into an action problem. An action problem is a discrepancy between the norm and reality, as perceived by the problem owner (Heerkens & Winden, 2017). The action problem is stated as follows:

"How should Instalsolutions increase the production rate from 22 to 40 final products per year and decrease the variation of the delivery times of the final products?"

The main goal of this specific research is to decrease the variability of the delivery times of the final products and increase the number of final products produced.

1.3 Research approach

To increase the production rate and decrease the variation of the delivery times of the sub-assemblies and final products some intermediate goals must be set up. To understand why these intermediate goals are chosen it is important to first get a better understanding of the current production procedure of Instalsolutions.

Before HoSt bioenergy systems bought a majority stake of Instalsolutions the company was hired by multiple external companies for different projects. For this reason, the company is set up as unit production. This means that the employees start working on one product, finish the whole product and then start working on the next product. Instalsolutions has only recently become part of HoSt biogas energy systems. Because of this, each time a sub-assembly is produced it is treated as a completely new product which has never been made before. Since each product is still treated as a completely new product there is no overview of which products are exactly needed for each final product and how much time it takes to produce each sub-assembly. Because of this, there is no clear working structure, this leads to high variations in production times. Since HoSt bioenergy systems bought a majority stake of Instalsolutions the focus of the company has been for 95% of the time on the production of biogas upgrading systems. For this reason, the first deliverable of this thesis is a working structure for the production of the sub-assemblies of Instalsolutions. The working structure should decrease the variation and lead to more structure within the production process of Instalsolutions in general. An example of how the production procedure could be set up is the first deliverable of this thesis which will answer the following sub-question:

"How can Instalsolutions decrease *variability of the throughput times of sub-assemblies and final products* by creating a clear working structure?"

The second intermediate goal of this research is finding the bottlenecks within the production procedure of Instalsolutions. The production process of Instalsolutions is arranged in a way to produce different products for different companies, recently the focus has changed to producing only four types of biogas upgrading systems. For this reason, the company expects that benefits can be achieved by rearranging the production process. Within this research, a simulation model will be created which represents the current production process of Instalsolutions. This simulation model is set up to find possible bottlenecks with the current production process of Instalsolutions. Furthermore, this model will investigate if Instalsolutions can increase the production rate by rearranging the production process. If it is beneficial the following sub-question will be answered:

"How should the production process of Instalsolutions be redesigned to increase the production rate?"

To make the outcome of this simulation measurable, the following KPIs are set up:

- Idle time per station and employee(s) grouped per welding certificate
- Influence on the efficiency of the workstation if smaller/bigger work in process spaces are created
- The bottleneck for the production process in general
- Influence on the production rate if an additional welder with a specific welding certificate is hired.
- The total throughput time of containers and sub-assemblies in the current situation and the rearranged situation.

We interchange the words "biogas energy system" and "container" during this thesis since the biogas energy system is built inside a shipping container.

Why these KPIs are chosen will be explained in more detail in Section 4.2.

In the third and last goal of this research, we will investigate more efficient ways to rearrange the warehouse structure of Instalsolutions. Since the company has quickly grown in the past year problems occurred within the warehouse. Most challenges that occur are caused by a lack of an overview of what parts are available at the warehouse and at which location the parts are placed/stored. To create more structure within the warehouse of Instalsolutions a lot of products are currently first ordered to the Netherlands where products are packed per project and then shipped per project to Poland. Because of this, the warehouse in the Netherlands is packed with products for Instalsolutions, this is one of the reasons why HoSt bioenergy systems wants all products directly delivered to Instalsolutions shortly. To make sure all products can be directly delivered to Instalsolutions more structure and warehouse space must be created. In this research we will investigate the following sub-question:

"How should Instalsolutions rearrange the warehouse to optimize the storage space within the current plant?"

1.4 Outline

In the remainder of this thesis, we will answer the following research question:

"How should Instalsolutions increase the production rate and decrease the variability of the throughput times of sub-assemblies and final products?"

The research is split into three sub-questions to answer this broad research question.

1. "How can Instalsolutions decrease *variability of the throughput times of sub-assemblies and final products* by creating a clear working structure?"
2. *"How should the production process of Instalsolutions be redesigned to increase the production rate?"*
3. *"How should Instalsolutions rearrange the warehouse to optimize the storage space within the current plant?"*

In the remainder of this thesis, the first section will show the research performed to create a clear working for Instalsolutions. The second section is focused on how to redesign the production process of Instalsolutions to increase production. The research performed on the optimization of the warehouse is always described in the third section.

In Chapter 2 the current situation of Instalsolution is represented. In Chapter 3 a theoretical perspective is created by performing an extensive literature review on the three sub-questions mentioned above. Chapter 4 is committed to the solution design. The results of this thesis are represented in Chapter 5. Lastly, the conclusion, recommendation, discussion, and future research are discussed in Chapter 6.

2. Current situation

In this chapter, the starting point of the research is described. In Section 2.1 the current working structure of Instalsolutions is provided. Section 2.2 states the current production process of Instalsolutions. The way the warehouse racks are currently placed within the warehouse spaces is represented in Section 2.3.

2.1 Working structure within Instalsolutions

The production process of Instalsolutions is currently structured as unit production. This means that the employees start working on one product, finish the whole product and then start working on the next product. Because of this, each time a sub-assembly is produced it is treated as a completely new product which has never been made before, which means there is not yet a clear working structure. Because of this, there is no clear step-by-step production flow within the current production process, this is caused by a lack of structure. Because there is no clear working structure a lot of time is lost by setting up the plan of approach, preparing the welding area, and deriving the exact measurements for each sub-assembly and final product. We assume this leads to high variations within the production times of sub-assemblies.

Since the whole production process is designed as unit production the focus of the data gathered is mainly to connect the right billables to the right project. The data regarding the production times, lead times or generalizing the production procedure is lacking since there was no need for this data until HoSt bioenergy systems brought a majority stake in Instalsolutions. To gather this data a more generalized working structure must be implemented. Once the data is gathered, we can investigate possible ways to minimize the variations in production time within the production process, which is discussed in the next section.

2.2 Production process of Instalsolutions

We will look at the production process of Instalsolutions. Before we can investigate possibilities to improve the production process of Instalsolutions it is important to first completely understand the production process which is currently executed at Instalsolutions. In this section, a short general overview of the company's way of working is given. Next to that, a more detailed overview of the actual production process is provided.

The general company overview is represented in Figure 2.

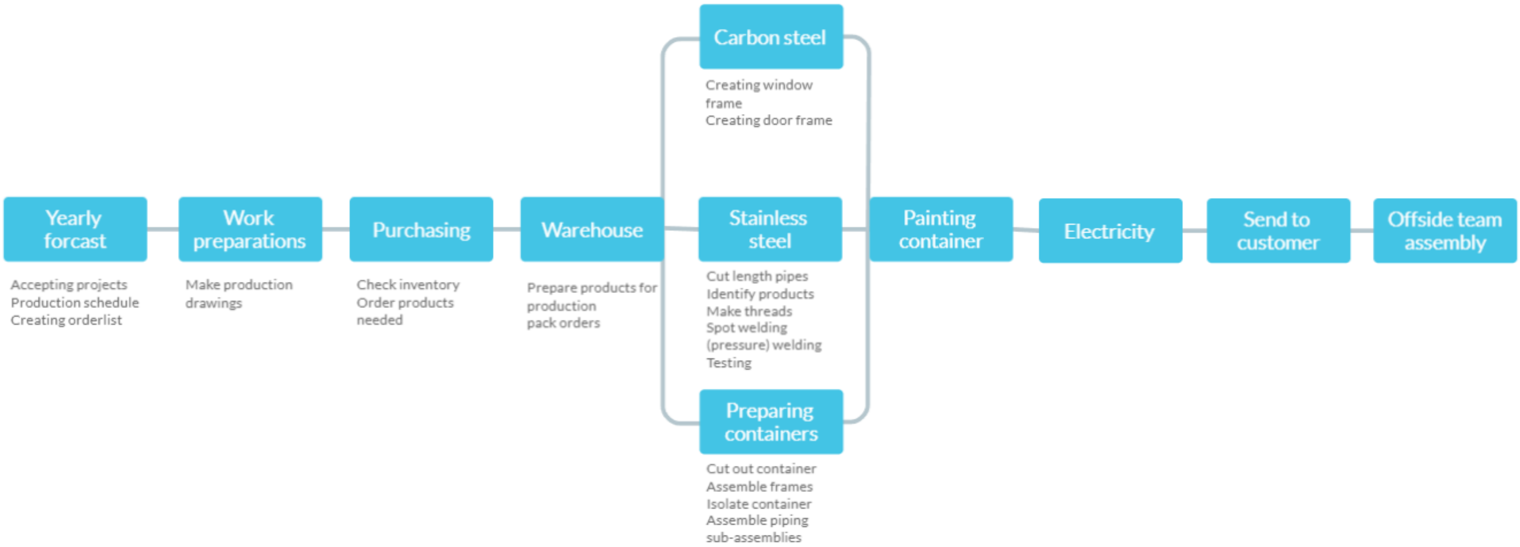


Figure 2 Company structure of Instalsolutions

At the beginning of the year, Instalsolutions receives a yearly forecast of projects requested by HoSt bioenergy systems. Instalsolutions decides, based on the end date of the projects, which projects will be accepted. Instalsolutions makes a production schedule of all projects which will be executed by Instalsolutions. Once a down payment is received the production drawings are created and the order list, based on the production schedule, is sent to the purchasing department.

The purchasing department checks which stainless-steel and carbon-steel must be ordered. Once the products are delivered the warehouse department places the products in the warehouse. When the production drawings are finished the warehouse department will start picking all products needed for production. Within the production, there are three different production lines. The stainless-steel production line, the carbon-steel production line, and the production line which is focussed on the assembly of the containers. The materials prepared by the warehouse are either for the carbon-steel production line or the stainless-steel production line. Within these two departments, the sub-assemblies are made. In the third production line, the sub-assemblies are assembled on the containers. After this, the container is painted by an external company, when the container comes back from painting no more welding can be done within the container. The next step is the electricity within the container and the biogas upgrading systems can be sent to the customer. Once the biogas upgrading system arrives at the customer an offside team will connect the biogas upgrading system.

To have a good understanding of the way the production process of Instalsolutions works, it helps to have an idea of what the production area looks like. Instalsolutions is mainly focused on the production of biogas upgrading systems. Within the biogas upgrading systems, there are four main types produced by Instalsolutions, which will be referred to as the 10-100, 10-300, 10-500, and 10-600. Each of the biogas upgrading systems consists of approximately 50 sub-assemblies of which 15 sub-assemblies are the same for each type of biogas upgrading system. These sub-assemblies are made to order for each container. An overview of these production lines and the production area can be found in Figure 3. The stainless-steel production line is displayed in grey, the carbon-steel production line is displayed in orange, and the assembly places of the containers are indicated in red. The sub-assemblies will be created in either the stainless-steel production area or the carbon-steel production area. Once the sub-assemblies are created, they will be assembled on the containers. The dark blue collar indicates the warehouse racks placed inside the warehouses.

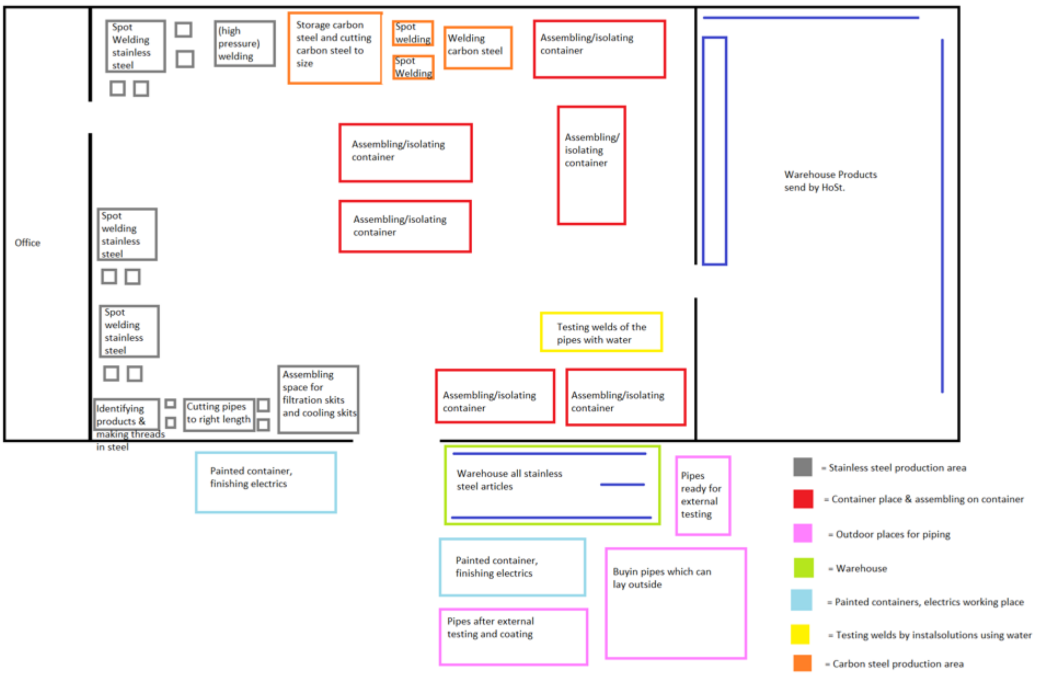


Figure 3 Production hall Instalsolutions

Now that we have an idea of the production area of Instalsolutions, we will have a closer look into the different production procedures of Instalsolutions. We first have a closer look at the assembly production line.

The preparation and assembly of the container consists of nine steps which are displayed in Figure 4. Within Instalsolutions, there are six places at which a container can be assembled. In Figure 3 the locations are marked in red.

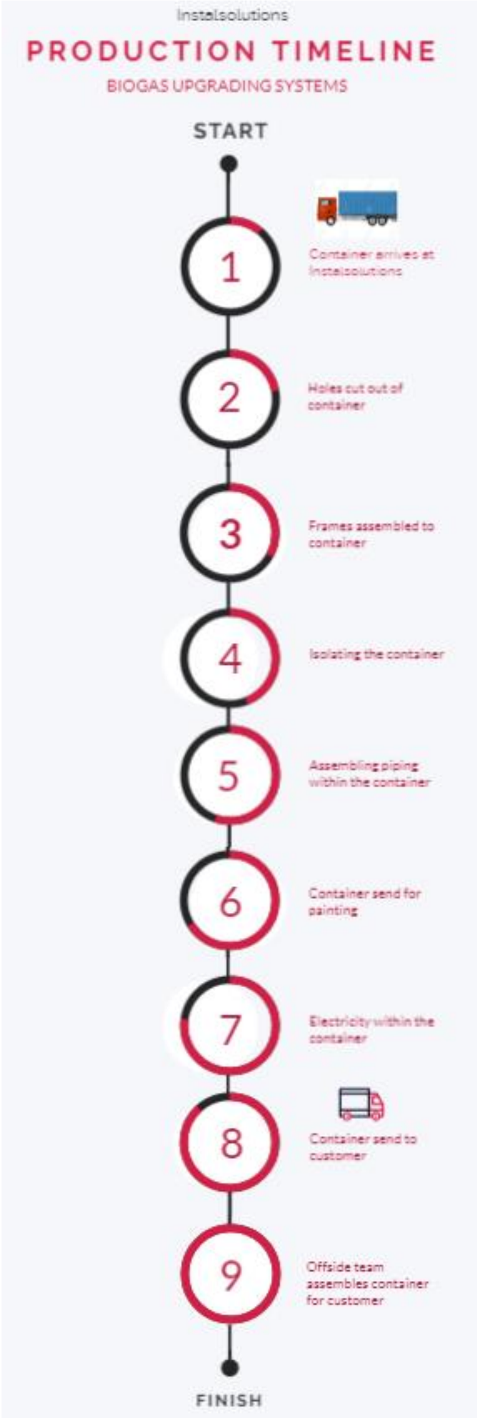


Figure 4 Assembly timeline of Instalsolutions

The first step of the production timeline is the arrival of the empty container at Instalsolutions. The containers are stacked at a warehouse approximately two kilometres away and are always in stock. Since the container is only two kilometres away the time of placing the container is negligible.

In the second step, the holes will be cut out of the container. These are mainly window frames and doorframes. Since mistakes are easily made within this step there are only a few people allowed to do this step. The time needed to cut out the frame of a 10-300 is 120 working hours.

In the third step, the sub-assemblies from the carbon-steel production line will be assembled on the container. This mainly consists of window frames and doorframes. The time needed to assemble the carbon-steel sub-assemblies on a 10-300 takes 143 working hours.

The fourth step in the production timeline is insulating the container. This is currently done at Instalsolutions by an external company. Instalsolutions allows a lead time for this step is five working days.

The fifth step is almost the same as the third step but instead of the carbon-steel sub-assemblies, the stainless-steel sub-assemblies will be assembled. The time needed to assemble all stainless-steel sub-assemblies to a 10-300 container will take a total of 266.2 working hours.

In the sixth step, the container is sent to an external company nearby. The container is painted and afterwards transported back to Instalsolutions. Including the transportation of the containers, a lead time of 5 working days is allowed for this step. Once the container is painted the container is placed outside and the container is finished outside the production area. In this way, there is already room for a new container in the production area at the beginning of step 6.

In the seventh step, the container is wired, and the electricity is attached. Furthermore, the container is tested to make sure everything is working according to plan before shipping the biogas upgrading system to the customer. This step takes on average 200 working hours to complete.

The eighth step is sending the container to the customer. Within the assembly production line, no steps are executed simultaneously.

The last step of the production timeline is assembling the container at the customer. This is done by an offside team and hence outside the scope of this research.

Before the stainless-steel and carbon-steel sub-assemblies can be attached to the container in steps three and step five, the sub-assemblies must be created. This is done in the carbon-steel and stainless-steel production lines. Which are explained in the next paragraph.

The production line of stainless-steel is depicted in Figure 5. Each component passes four stations. At every station, a wooden box is placed. In each wooden box articles for assemblies are placed. The boxes also function as an intermediate buffer within the production line, within the figure this is indicated by the blue boxes. In the first station, the pipe is cut to the necessary length. In the second station, threads are made within the piping. The third station is spot welding, there are two stations at which spot welding can be done simultaneously. After this, the sub-assemblies are either forwarded to the station pressure welding or the station normal welding. The working stations are identical, this is solely depending on the certificates of the welder. The station pressure welding can also be used for normal welding but not the other way around. The station to sort which components need pressure welding and which components need normal welding is indicated by the blue with grey square before the welding and pressure welding station.

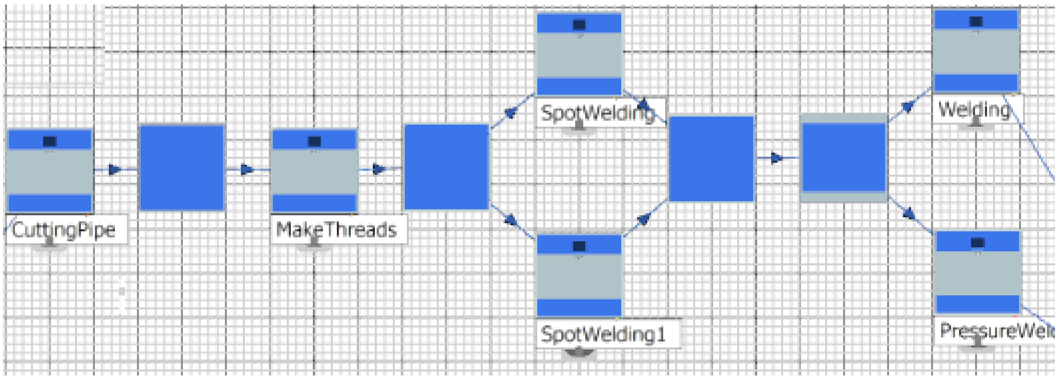


Figure 5 Stainless-steel production line

The carbon-steel production line is shown in Figure 6. The production line works quite similar to the stainless-steel production line, but threads and pressure welding are not necessary, hence the stations making threads and pressure welding can be taken out of the production line.

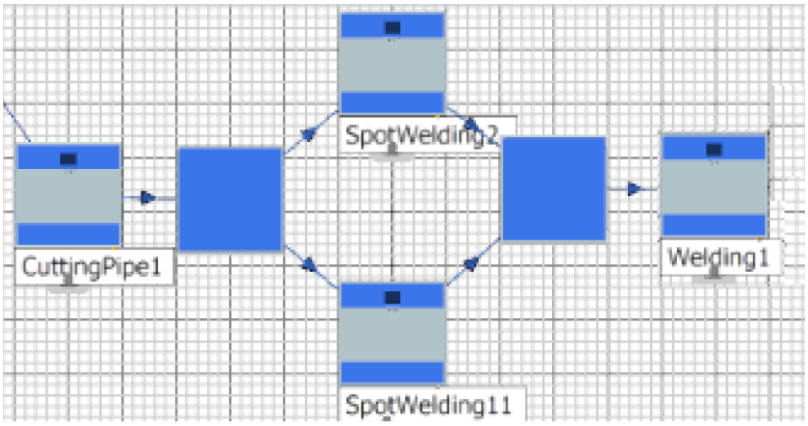


Figure 6 Carbon-steel production line

The carbon-steel production line and stainless-steel production line must be strictly separated from each other since the carbon-steel metal will affect the stainless-steel metal. Furthermore, the order in which the steps are executed is important and cannot be interchanged.

Once the sub-assemblies are finished, they are brought to the assembly production line.

2.3 The warehouse of Instalsolutions

Since the company has grown quickly in the past year the warehouse of Instalsolutions ran into some challenges. Most issues that occur are caused by a lack of an overview of what parts are available at the warehouse and at which location the parts are. To create more structure within the warehouse of Instalsolutions a lot of products are currently first ordered to the Netherlands where products are packed per project and then shipped per project to Poland. Because of this, the warehouse in the Netherlands is packed with products for Instalsolutions, which is one of the reasons why HoSt bioenergy systems wants all products directly delivered to Instalsolutions on short notice.

Other reasons for looking into redesigning the warehouse are the unnecessary transport kilometres and the unnecessary costs to transport the products to the Netherlands and further to Poland. This is not the only challenge the warehouse department of Instalsolutions is facing. During this research, we investigate the possibilities of increasing the company's production rate by making sub-assemblies on stock. This means that the sub-assemblies must be stored at the warehouse of Instalsolutions. To prevent future problems within the warehouse research will be conducted to optimize the warehouse space within the warehouses of Instalsolutions.

Currently, Instalsolutions has three warehouses. The first and biggest warehouse discussed is located in the production hall, as can be seen on the right side of Figure 3. Once a delivery from HoSt bioenergy systems arrives the articles which are already attached to a project are placed in boxes with the project name on them. The boxes are placed in the first warehouse together with the products sent from HoSt bioenergy systems. In the current situation, there is no overview of what is inside each box. The warehouse racks (displayed with W) are placed as indicated in Figure 7. The warehouse has a length of 12 meters and a width of 10.5 meters

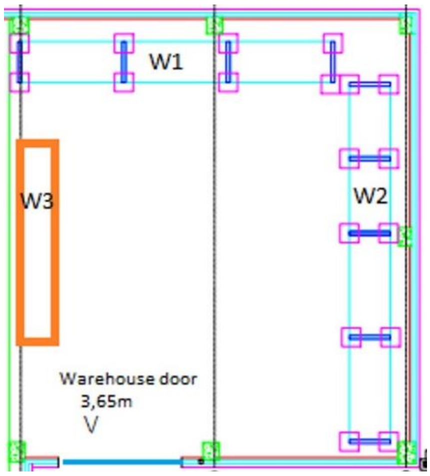


Figure 7 Layout warehouse

Rack 1 (W1)	Rack 2 (W2)	Rack 3 (W3)
L = 1068 cm	L = 906 cm	L = 600 cm
H = 520 cm (130 per shelf)	H = 520 cm (130 per shelf)	H = 250 cm
D = 110 cm	D = 110 cm	D = 80 cm

Table 1 Measurement racks warehouse

W1 has support beams every 267 cm
W2 has two support beams every 186 cm and two support beams every 267 cm

Hence in the current situation, Instalsolution has at most space for 100 standard pallets of 122 cm × 102 cm.

The second warehouse at Instalsolutions is a large tent located in front of the production area. In Figure 3 this tent is indicated as “warehouse stainless-steel articles”. Within this warehouse, the small articles and stainless-steel articles are located. Within the tent, each article is provided with an article number and has a fixed storage place. The racks in the warehouse are represented in Figure 8. The length of the tent is 20 meters, and the width is 5 meters. The height of the tent in the middle is equal to 3.5 meters and the height of the tent on both sides is equal to 2.6 meters.

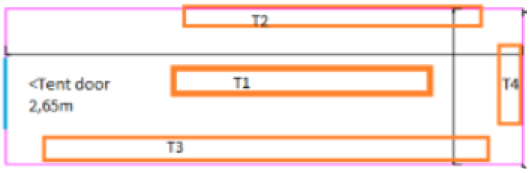


Figure 8 Layout tent warehouse

Rack 1 (T1):	**Rack 2 (T2):**	**Rack 3 (T3):**	**Rack 4 (T4):**
Length = 760 cm, supports beams every 190 cm	Length = 950 cm, supports beams every 190 cm	Length = 1520 cm, supports beams every 190 cm	Length = 255 cm, supports beams every 85 cm
Hight = 232 cm, first shelf at height 100 cm, then 3 shelves every 44 cm	Hight = 232 cm, first shelf at height 100 cm, then 3 shelves every 44 cm	Hight = 232 cm, first shelf at height 100 cm, then 3 shelves every 44 cm	Hight = 232 cm, supports beams every 100 cm
Depth = 90 cm	Depth = 90 cm	Depth = 90 cm	Depth = 90 cm

Table 2 Measurements racks tent

The third and last warehouse at Instalsolutions is located approximately 2 kilometres away from the production area. The warehouse consists of the storage of containers. Instalsolutions started renting the third warehouse when they ran out of space at the production plant. There is no structure or racks within the third warehouse.

2.4 Conclusion

In this chapter, the current situation of Instalsolutions is discussed. Section 2.1 expresses that Instalsolutions used to be hired by external companies for single projects. Because of this, the production process of Instalsolutions is organized as unit production. Therefore, each time a sub-assembly is produced it is treated as a completely new product which has never been made before, which means there is not yet a clear working structure. Because of this, there are high variations between production times which makes it harder to collect necessary data. In Section 2.2 we have a closer look at the production flow of Instalsolutions. Furthermore, the plant layout is discussed, and we have a close look at the different production lines. In the current situation, a lot of buy-in products are first delivered to the headquarters in the Netherlands, where the products are sorted per project and then sent to Instalsolutions. This is done since Instalsolutions had difficulties within the warehouse department. For this reason, the current warehouse design is discussed in Section 2.3. In the next chapter, a systematic literature review is performed. In Section 3.1 we gather knowledge on how to create a standardized working structure. In Section 3.2 we investigate possible optimization steps within the production process of Instalsolutions. Lastly, Section 3.3 creates an overview of which safety rules must be met within a warehouse and we investigate how the storage space within a warehouse can be optimized.

3. Literature review

Before coming up with a solution, a theoretical perspective is created. To come up with a good theoretical perspective, an extensive systematic literature review is performed. The results found are discussed in this chapter. In Section 3.1 a literature review is performed regarding the 5S management method. A systematic literature review regarding delayed product differentiation and minimizing idle time within the production process is performed in Section 3.2. Lastly, Section 3.3 states what must be taken into consideration when designing a warehouse layout.

3.1 Creating a clear working structure for Instalsolutions

In this section, we will investigate how to improve the working procedure of Instalsolutions. This will be done by performing a literature review on lean management theories. This is necessary since in the current situation the production of each product is treated as if a completely new product must be created. Because of this a lot of time can be saved by creating a standard working structure based on lean management theories. Furthermore, the standard working procedure is necessary to provide us with the data needed for the second and third deliverables.

To determine how to create a clear and efficient working structure for Instalsolutions we delved into different lean management theories. Lean management theories represent a set of principles and techniques to identify and eliminate waste in manufacturing processes. One of the lean techniques is the 5S management technique, the 5S stand for Sort, Simplify, Shine, Standardize and Sustain. (Patel & Thakkar, 2014). The 5S philosophy focuses on simplification of the work environment, effective workplace organization, and reduction of waste while improving safety and quality (Korkut et al., 2009). The 5S technique is a structured program to systematically achieve total organization cleanliness and standardization in the workplace. Implementing the 5S technique will result in a clean workplace with higher productivity, high-quality products, reduced costs, and ensure timely delivery and consequently, a safe workplace (Patel & Thakkar, 2014). We will have a closer look at the 5S' of the 5S management technique.

Sorting:
Since Instalsolutions used to be a manufacturing and assembly company for a lot of different companies a new inventory list must be created of which products are exactly needed to produce the biogas upgrading systems. This is done in the sorting stage. The first step is to systematically segregate and dispose all items, materials, scraps and screws which are not needed anymore. The separation process helps to determine if the necessary materials are present and what to order in the future. All unnecessary items within the production area will be disposed of. This will lead to a small(er) list of buy-in articles which must be applied to the working procedure, see Section 4.1. Furthermore, this creates a clear overview of what must be stored in the warehouse area (Sorooshian et al., 2012).

Simplify:
Especially important is a visualization of the workplace. This helps to focus on which tools and materials are needed for each workstation. Tools, equipment, and materials must be systematically arranged for the easiest and the most efficient access (Khedkar et al., 2012). This will improve the process and increase its effectiveness and efficiency. The main objectives of simplification are forming a neath workplace, avoiding time loss while searching the material and decreasing the number of mistakes in the production process (Rojasara & Qureshi, 2013). This will shorten the times of seeking necessary things and increase the safety level since people are spending less time walking around and searching for things.

Shine:
Point outs the need and necessity of a clean and neat workplace. Cleaning should become a daily activity. The dust, dirt and wastes are the sources of untidiness, indiscipline, inefficiency, faulty production, and work accidents. Therefore, workplaces should be cleaned at regular intervals. Every tool and equipment should be restored in its place after its use (Harsha et al., 2013). The benefits of a clean workplace are readily apparent after a short period. Employee motivation increases and the most productive time can be dedicated to the most important tasks. This indicates the importance of a fixed storage place for all products. This starts by creating a structured and neat warehouse, see Section 4.1.

Standardize:
The goal of this step is to create a standardized workflow which means the necessary systems are formed to maintain the continuance of good practices in the workplace (Korkut et al., 2009). This will increase safety and reduce industrial pollution. When we discuss standardizing the workplace the work procedure must be defined and each article must look the same independent of who produced the article. A general guideline for this is provided in Section 4.1.

Sustain:
Train employees disciplined for practising the 5S system continuously so that the habits and culture are engaged within the organization (Sorooshian et al., 2012). This is a difficult step which can only be done by the company itself. We can only express the benefits and importance of the 5S but the company has to sustain the 5S eventually.

The benefits of training the employees regarding the 5S method are:

- Increasing awareness and motivation.
- Decreasing mistakes resulting from inattention.
- Improvement of the internal communication processes.
- Improvement in the interaction of human relations.

To express some additional benefits from implementing the 5S management technique which is not directly connected to one of the S's we will look at the results of some case studies which are performed on similar manufacturing companies as Instalsolutions. The results expressed in percentage differ a lot between case studies since this is dependent on the starting point of the company before the 5S management technique was implemented.

- Low idle period and downtime, breakdown reduction, waste elimination or minimization are some of the secondary benefits of 5S implementation. (Grupta, 2021)
- A study on the implementation of 5S in a product manufacturing company drastically reduced the inspection time of components and the number of accidents (Subburaman, 2019).
- In an important study where 5S was implemented in the small-scale manufacturing industry, the part production rate was increased up to 15% because of the search time reduction (Kuchekar et al., 2019).
- In a metalworking company, the 5S technique is found effectively useful for both production as well as quality. Workers' efficiency was improved, and the occurrence of mistakes was reduced with improved ergonomics and workplace safety (Costa et al., 2018).
- In an interesting study, Mane and Jayadeva (Mane & Jayadeva, 2015) utilized 5S as a tool to facilitate lean manufacturing and total quality management in a small-scale tooling manufacturer. Drastic improvement in space availability up to 70% was achieved after

implementing 5S. The high-performance rating was also observed after comparing pre- and post-implementation audits.

There are plenty more examples which show that implementing the 5S principles in a production process will lead to high space savings, a decrease in searching time, decreased idle times and better motivation among the employees. Furthermore, this will lead to a decrease in variation within the production time. Hence it is important to take the 5S principles into account when we set up the working structure. The working structure creates a more standardized production process which will make it easier to gather data regarding, for example, the production times for each sub-assembly. The data is needed for the second deliverable, the simulation model of the production process.

3.2 Variability within a production process

In Section 3.1 we explained why a standard working procedure is necessary and how this will provide us with data regarding the production times for each sub-assembly and the production times of the nine steps discussed in Section 2.2. Within this section, we will perform literature research on how to optimize the production process of Instalsolutions. Instalsolutions is currently producing everything to order, which makes sense since Instalsolutions used to be hired for single projects by external companies. In the new situation, Instalsolutions is mainly focused on the production of biogas upgrading systems. Because of this, we investigate the possibilities of starting partial make-to-stock production to decrease the variation and minimize the idle time within the production process. Completely make-to-stock production is not possible since small adjustments can be made by the customer. We will refer to the partial make-to-stock production strategy as delayed product differentiation.

Instalsolutions is dealing with the challenge to fulfil customer orders quickly (responsiveness), as well as offer customized products. However, the need to have high product variety and quick response time places conflicting demands on the production system (Feitzinger & Lee, 1997; Fisher et al., 1999; Lee, 1996). For this reason, there are four types of biogas upgrading systems that Instalsolutions produces based on a Make-To-Order (MTO) production schedule. In the MTO model, production is not initiated until a customer order is received. While this strategy eliminates finished-goods inventories and reduces a firm's exposure to financial risk, it usually spells long customer lead times and large order backlogs. To decrease the long lead times and backlogs the production could shift to a Make-To-Stock (MTS) mode of production. In that case, the items are produced ahead of demand and kept in stock, ready to be shipped upon receipt of orders. This becomes costly when the number of products ordered is large. It is also risky when demand is highly variable. The delayed differentiation production strategy is a hybrid strategy in which a common product platform is built to stock. It is differentiated, by assigning to it certain customer-specific features, only after demand is realized. Hence, manufacturing occurs in two stages, firstly, the MTS stage where one or more undifferentiated platforms are produced and stocked; and secondly the MTO stage where product differentiation takes place in response to specific customer orders (Gupta & Benjaafar, 2004).

The delaying differentiation strategy has several benefits. Since semi-finished goods are made to stock the order-fulfilment delay reduces relative to the pure MTO system. Since many different end products have common parts, holding semi-finished goods inventory benefits from demand pooling. Pooling is the concept that the variability in demand for raw materials or semi-finished goods can be reduced by aggregating demand across multiple products. Because of this lower inventory levels can be maintained to achieve the same service-level performance of a comparable system with no pooling (Eppen, 1979). Further benefits of the delayed product differentiation are that the MTS segments can be further streamlined within the manufacturing process. This makes it easier to create a simplified product scheduling, sequencing, and the purchase of raw materials (Gupta & Benjaafar, 2004).

A system that is closely related to the model of Instalsolutions was modelled by Aviv & Federgruen, (2001a, 2001b). A two-stage system is considered in which stage 1 produces undifferentiated items that are after the customer order decoupling point differentiated in stage 2. The lead times in both stages are assumed to be constant. In Aviv & Federgruen (2001a), both stages have no capacity constraint, whereas, in Aviv and Federgruen (2001b), stage 1 has limited capacity (Gupta & Benjaafar, 2004).

From Aviv & Federgruen (2001a, 2001b) the following can be concluded. When a high utilization is realized in either stage 1 or stage 2 a delaying differentiation strategy is less desirable. This can logically be explained since if there is tight capacity planning in the second stage the delaying differentiation system has a higher inventory to avoid shortages. Since the second stage does not carry inventory in the delaying differentiation the stock of the first stage becomes more important. This means that the delayed differentiation strategy becomes inferior to pure MTS if the utilization is sufficiently high. The effect of a tense capacity at the first stage is more subtle. A higher stage 1 utilization causes higher congestion. Consequently, the experienced lead times of stage 1 have a large dependence. An increased positive dependence in turn diminishes the value of the inventory pooling. Aviv & Federgruen (2001a, 2001b) observe that having a tighter capacity in the second stage negatively affects the desirability of delaying differentiation (Gupta & Benjaafar, 2004).

A multistage production system such as the one used at Instalsolutions has three types of inventories. First, the Work-In-Process (WIP) inventory, second a semi-finished goods inventory and last, a finished-goods inventory. The WIP inventory consists of raw materials or semi-finished products that are waiting for the next working stations, the products are not finished yet. The WIP is placed inside the wooden boxes (see Section 2.2). The items will be finished when the workstation becomes available. The semi-finished goods are stored in the warehouse (see Section 2.2), this is the inventory between two production stages. In our case then semi-finished goods define the boundary between MTS and MTO production line, also known as the push-pull boundary (Gupta & Benjaafar, 2004) or the customer order decoupling point. Once the semi-finished goods are requested by the MTO production line, it will be referred to as WIP inventory there. In our case, the semi-finished goods inventory is transferred to the assembly production line in step 2 or step 4 of the assembly production line, which can be found in Section 2.2. The removal of semi-finished and finished goods is driven by demand from the immediate downstream stage or customers.

Since in the situation delaying differentiation strategy sub-assemblies are made to stock more storage space within the warehouse must be created. In the next section, we will investigate the safety measurements which must be taken into consideration when designing a warehouse layout.

3.3 Principles for designing a warehouse layout

Based on the conducted interviews with the employees of Instalsolutions and observations made in Poland it can be concluded that benefits can be gained by improving the warehouse structure of Instalsolutions. This is substantiated by the results of the research from Section 3.2. Hence this will be the focal point of our last deliverable. To determine how a future warehouse should be designed, we researched what professionals and academics in the field of designing warehouse layouts recommend taking into account.

"How should Instalsolutions rearrange the warehouse to optimize the storage space within the current plant?"

To answer this research question, this section is split up into two subsections. In the first subsection, we will discuss the safety regulations which must be considered when designing a warehouse. In the second subsection, the literature review is performed on how to design a warehouse.

3.3.1 Safety rules which must be complied with when designing a warehouse

Before the warehouse can be rearranged more information must be gathered regarding the safety rules within a warehouse. In this way, a list of rules can be created to which the warehouse must comply. This must be taken into consideration when designing the new warehouse structure of Instalsolutions.

Since no European safety regulations regarding the warehouse could be found we decided, in consultation with the company supervisor, that the Dutch safety regulations will be applied. This is done since we expect that the Dutch safety rules are stricter than the Polish safety rules. Furthermore, HoSt bioenergy systems is a Dutch company and hold most of the stocks of Instalsolutions. The last reason why the Dutch safety regulations are applied instead of the Polish safety regulations is the language barrier.

We will first discuss some general rules which must be met when a warehouse is designed. Firstly, the warehouse racks must be properly assembled of materials suitable for the purpose and reinforced both longitudinally and transversely by cross-beam connections. When warehouse racks are higher than two meters and the height to depth ratio exceeds 4:1, the racks must be linked to the building or each other. Furthermore, the permissible floor and rack load must be known and indicated. The distances between the racks and the width of the aisles must be sufficient to allow unhindered operation. This is mainly caused by the type of forklift truck or reach truck used within the company (Stichting Arbo en Podiumkunsten, 2007; Verduijn, 2022). The height of the warehouse racks depends on the space between the sprinklers and your product, to comply with fire codes a space of 46 to 61 cm is required (International Code Council, 2021).

Secondly, we will discuss some safety rules which must be met regarding the beams of the warehouse racks. Firstly, all beams with a length of 304 cm or more should be tied together with at least one front-to-back support except when solid decking panels are used. All beams must conform to the standards set by the latest Rack Manufacturers' Institute load and resistance factor design Specifications. Furthermore, a clearance of 10 cm between palletized loads and between loads and uprights is recommended. The clearance should be sufficient to accommodate minimum pallet overhang and tolerances – where pallet placement may vary. Additional clearances may be required to accommodate building structures or intermediate sprinkler systems (according to local codes). Lastly, racks should be level, plumb and properly anchored to ensure minimum stability standards (Kramer, 2022)
A clear overview of the safety rules mentioned above are also displayed in Figure 9.

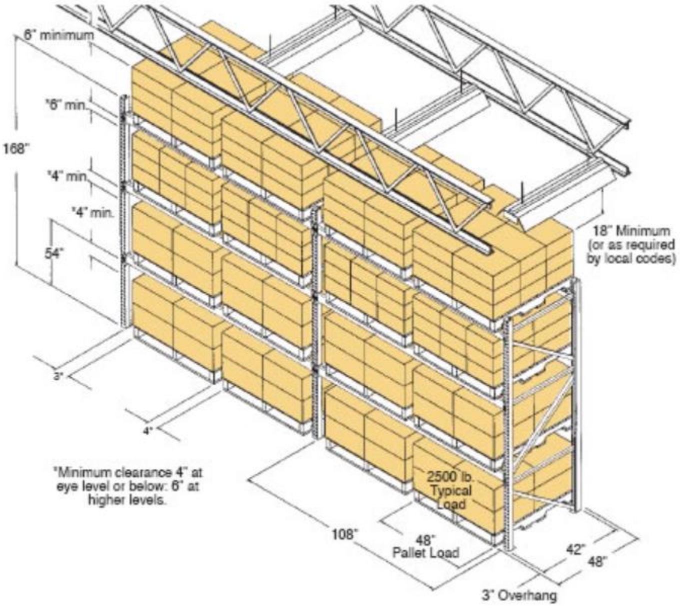


Figure 9 Overview safety rules

(Kramer, 2022)

Now we are aware of the safety rules that must be considered when designing a warehouse layout. Information about different methods of designing a warehouse layout can be gathered.

3.3.2 Optimizing the available warehouse space

The policy for a storage location assignment can be classified into three categories, randomized, dedicated, and combined. In a dedicated storage policy, each product has a fixed storage location based on the characteristics of the product. The randomized storage policy assigns each product to a random location (also called "chaotic"), in this way the space utilization is maximized. Within the combined storage policy each product has a fixed storage place, but some random factor is used to improve the space utilization of the policy. For the implementation of a randomized storage policy, the dimensions of each article must be modelled within the policy (Muppani & Adil, 2008). Instalsolutions is a relatively small organization which implemented article numbers within the last year. Because of this, it is not profitable to implement a randomized or combined storage policy, hence these policies are not further discussed within this thesis. Within Instalsolution major steps are taken if we can create fixed storage places for each article and sub-assembly. Hence, further information is gathered regarding the dedicated storage policy.

In the dedicated storage policy, a fixed storage location is reserved for each item of a single product during the entire planning period. The reserved warehouse space must be equal to the maximum inventory level of each product. The benefits of the dedicated storage policy are that the location and management of items can be done by hand under relative stable demand conditions. The policy is relatively simple to implement, the policy is static, which means it does not have an explicit time effect. The main con of the dedicated storage policy is that storage space can be used more efficiently, which is a disadvantage since the storage space at Instalsolutions Is limited. (Fumi et al., 2013)

When we investigated the way to optimize the storage locations in a dedicated warehouse setting. We found out this is often referred to as a fixed warehouse setting (de Koster et al., 2007) this means the characteristics such as storage capacity, functional area sizes, product range, material handling costs and demand patterns are predetermined. Finding the optimal storage location for a fixed warehouse is referred to as the Storage Location Assignment Problem (SLAP)(de Koster et al., 2007). The SLAP is concerned with assigning the products optimally to storage locations in a fixed warehouse setting.

When an optimal policy for a fixed warehouse setting is created, it is measured by two indicators: first, the space utilization and second the total travel time of both storage and retrieval operations.

1. Space utilization

The foundation and relatively fixed storage capacity in a warehouse is a direct consequence of the layout and equipment such as the rack and shelving. To optimize the storage capacity of each warehouse an understanding of the inventory that will be stored in it and the expected frequency of how often an item is required.

A ratio was developed to calculate the storage capacity of a warehouse. This ratio is based on the cubic storage space when the materials are stored on the floor divided by the total cubic volume of the warehouse. (Benson, 2013)

To determine the volume of a building we measured the dimensions of the inside measurements of the warehouse, the length, the width, and the maximum stack height. This is the total warehouse space we can work with. Based on the characteristics of the inventory and the material handling such as the type of forklift truck, the sprinklers and placement of lighting requirements we can develop several layout options within this space.

For each warehouse we calculated the storage capacity based on drawing multiple layout possibilities within the warehouse space, this is the total, theoretical storage capacity. The dimensions of the pallet racks which are drawn in the warehouse layout are described above.

When calculating the storage capacity, the result usually ranges between 22% and 27%. Warehouses with results outside that range typically have unusual characteristics (Benson, 2013). This ratio gives us an interpretation of how good the designed warehouse layouts are.

2. Total travel time of both storage and retrieval operations.

There are a lot of layouts that have an average travel distance close to the optimal travel distance, as proven by Roodbergen & Vis (2006). Instalsolutions is a manufacturing company in which the travel time of storage and retrieval operations are only a small part of the operation. For this reason, the time saved by determining all possible walking routes and setting up a linear program to minimize the storage and retrieval operations is limited. Hence minimizing the total travel time of storage and retrieval operations will be outside the scope of this research. Some general founding will be taken into consideration when designing the warehouse layout. Examples of this are that it is optimal to locate the depot in the middle of the front cross aisle and that the depot location is restricted to the front cross aisle (Roodbergen & Vis, 2006). This makes sense in the case of Instalsolutions since the only way to the production area or loading area is in the front of the warehouse.

(Roodbergen & Vis, 2006) compared over 2500 different warehouse layout problems and found that the largest gap routing performed better than or equal to S-shape routing in all situations if the optimal layout was used for each routing method. The optimal layout is sensitive to the routing policy used in the optimization. They found efficiency losses of up to 18% when optimizing the layout for another routing policy than was used for the actual operation.

3.4 Conclusion

In Section 3.1 we gather knowledge on how to create a standardized working structure, this is done by investigating the 5S management theories. In Section 3.2 we investigate possible optimization steps within the production process of Instalsolutions. More specifically, we investigate the possibilities of starting partial make-to-stock production to decrease the variation and minimize the idle time within the production process. We will refer to the partial make-to-stock production strategy as delayed product differentiation. Lastly, Section 3.3 creates an overview of which safety rules must be met within a warehouse and we investigate how the storage space within a warehouse can be optimized. In Chapter 4 we will apply the knowledge gained to Instalsolutions.

4. Solution design

In this chapter, we start working towards the solutions of our research. In Section 4.1 benefits of the working structure are addressed. In Section 4.2 the production process is rearranged, and the simulation is discussed. The redesigned warehouse layouts are mentioned in Section 4.3. Lastly, Section 4.4 investigates the influence of variability within the production process of Instalsolutions.

4.1 Work structure of Instalsolutions

Since HoSt bioenergy systems has acquired a majority stock in Instalsolutions the company is focussing on the production of four different products 95% of the time. This changes the way Instalsolutions should operate since for each product the company produces the products can now be standardized. For this, a work structure is a prerequisite. The working structure will be based on the 5S management technique. Research performed on the 5S management technique can be found in Section 3.1. Implementing the working structure will have the following benefits:

The working structure must create a clear overview of all articles needed for each sub-assembly. This automatically generates a list of all products which must be available in the warehouse. This also means that the articles not on that list are not needed in the warehouse. These articles should be sorted, and the unnecessary articles should be disposed of. This will help create a clean working area and decrease the searching time for products (Sorooshian et al., 2012). Furthermore, this will help the purchasing department to create an overview of all articles needed and how often which articles are needed. Sorting the products needed for production is the first step in implementing the 5S management technique.

The visualization of the end products at the working structure will help the welder. This will improve the effectiveness and efficiency of the MTS production line and reduce errors (Rojasara P.M. & Qureshi M.N., 2013). Further visualization within the production process, such as the visualization of where tools must be placed but could be realized once the working structure is up and running. These are all results of simplifying the working space, the second of the 5S management technique.

All input products for each sub-assembly are clearly stated in the working structure. Because of this, the worker has a clear overview of which tools and products are needed to make the sub-assembly. This will help to create a clean and neat working space (Lingareddy H. et al., 2013). This helps to realize Shine, the third of the 5S management technique. Additional improvements, such as floor stock, are relatively small steps which can easily be implemented after the implementation of the general principle of the 5Ss as described in this thesis.

The fourth step of the 5S management technique is to standardize the workflow. This is done by creating a step-by-step working structure which is written on the working procedure. This will increase the safety of the working space and reduce industrial pollution (Korkut et al., 2009).

The last step of the 5S management technique is to discipline the employees to sustain the changes. This must be done by training the employees of Instalsolutions and explaining the benefits of the 5S strategy. This can only be done by Instalsolutions.

Furthermore, some overall benefits of the 5S management technique which are not directly related to a specific S are mentioned below:

- A decrease in the variability of the production times of sub-assemblies (C. Patel & Thakkar, 2014).
- Create more insight into whether a project will be finished on time or not (C. Patel & Thakkar, 2014).

- Increasing the efficiency of all processes sustained by a reduction in search time (Kuchekar et al., 2019).
- Minimization or even elimination of losses in the company (Grupta, 2021).
- Smoother process flow within the production process (Costa et al., 2018).
- The quality control will be increased (Subburaman, 2019).
- The safety and security of the working space will be increased (Subburaman, 2019).

In the current situation Instalsolutions is only focused on the production of four different products, the 10-100, the 10-300, the 10-500 and the 10-600. If, for example, the 10-600 must be produced for each sub-assembly the production drawings must be recreated. Then the production leader together with the warehouse leader must gather all buy-in products needed, the welder must come up with a plan on how to produce the sub-assembly, and then the start-up time and clean-up time must be considered. To reduce the time needed and decrease the variation in production time to produce sub-assemblies a clear working structure should be made for each sub-assembly. In Section 5.1 the working structure for the B0000-tek10-005 is represented. When we created the working structure the goals and benefits of the 5S management techniques were taken into account.

Once Instalsolution implemented the working structure for the sub-assemblies the production flows are better specified. Because of this, it should be easier to gather information regarding the production time of each sub-assembly. The data gathered will be used in this research's second and third deliverables. In the second deliverable, we will look at optimizing the production process of Instalsolutions. For this step, the following data must be gathered:

- Production time of Instalsolutions for each sub-assembly specified per working station as specified in Figure 5 and Figure 6.
  - Cutting pipe
  - Thread making
  - Spot Welding
  - Actual welding
  - Pressure welding
- Welding certificate needed for each sub-assembly
- Welders working at Instalsolutions, and which certificate each welder has
- Which sub-assembly is made by which department (stainless-steel/carbon-steel)
- Time needed to assemble each sub-assembly to the container
- Time needed to cut out holes of container (10-100, 10-300, 10-500, 10-600)
- Time needed to assemble frames to the container (10-100, 10-300, 10-500, 10-600)
- Time needed to insulate the container
- Time needed to assemble the piping sub-assemblies to the container.
- Number of people qualified and available to work on the assembly of sub-assemblies, cut out holes, assemble frames, insulate and assembly piping to containers at Instalsolutions?

This data is needed for optimizing the flow of the production process of Instalsolutions. This will be done by creating a model in Plant simulation which reboots the current MTO working procedure of Instalsolutions and the working procedure of Instalsolutions rearranged as a delaying differentiation strategy. The goals of the simulation model are to analyse and optimize the production process of Instalsolutions. The model supports objective decision-making using dynamic analysis, to enable managers to safely plan their operations and save costs.

Based on the working procedure described above also the buy-in products can be standardized and data can be gathered which will be needed to design an efficient and structured warehouse layout. To decide the location of the products within the warehouse the following data must be gathered:

- The size of the raw materials
- The weight of the raw materials
- The frequency a product is used, will be split up into high usage, normal usage, and low usage.
- The location of rejected products
- The location of the production line at which the raw material is needed
- The safety stock needed based on:
    - Lead times buy-in products
    - Production time
    - Measurement of the products

Once this data is collected a new arrangement of product location within the warehouse can be created. The benefits of rearranging the warehouse structure are:

- The space utilised in the storage department
- Timesaving in finding materials
- Increase work environment
- Increase employee performance and motivation (C. Patel & Thakkar, 2014).

4.2 The production process of Instalsolutions

In this section, we will investigate the possible advantages of rearranging the current, MTO production process, as the delayed differentiation production process. In the current situation, we wait with producing sub-assemblies till the container arrives. In this situation, the variability of the production of sub-assembly must balance out before steps three and five of the assembly production line, which can be found in Section 2.2. Otherwise, this will cause a delay in the production process. A solution could be that the stainless-steel production line and carbon-steel production line will start production as MTS. The production line focused on the preparation and assembly of the container will still be arranged as an MTO production line. This is necessary since some customers have special requests or demands and because of the high value of the end products. In this case, the production process is rearranged as a delaying differentiation strategy. In this way, the variability in production times of the sub-assemblies will cancel each other out which might result in a steadier production flow. To substantiate this expectation a model in Plant simulation will be created. In the beginning, the model will represent the current production process of Instalsolutions as described in Section 2.2. Then the model will be adjusted in such a way that the delayed differentiation production process will be represented. To decide which production process is beneficial information based on the following KPIs will be gathered in the current production process and the delayed differentiation production process:

- Idle time per station
- Idle time for an employee(s) per certificate
- The bottleneck for the production process in general
- The total throughput time of containers in the current situation and the throughput time in the situation sketched above.

The parameters we can influence within the simulation model are

- The influence of allowing a low or higher amount of work in process.
- Influence of hiring an additional welder with a specific certificate.

The only changes within the model are that the carbon-steel and stainless-steel production lines will no longer wait till the container is levelled before they start the production of the sub-assemblies. The carbon-steel and stainless-steel production line will start producing the sub-assemblies at a constant flow independent of the demand, according to the work procedure described in Section 4.1. In other words, the stainless-steel and carbon-steel production lines are push systems while the assembly line is still a pull system. One of the benefits of rearranging the stainless-steel and carbon-steel production lines as push systems is caused by the fact that different end products have common parts. Because of this holding semi-finished goods inventory benefits from demand pooling. For this reason, lower inventory levels can be maintained to achieve the same service-level performance of a comparable system with no pooling (Eppen, 1979).

Within the simulation, the warehouse will not be modelled. We choose not to model the warehouse because only limited time should be spent on gathering the items from the warehouse once a fixed warehouse layout is determined. Next to this, the warehouse department will be responsible for preparing the items for production and hence is outside the scope of this research.

The simulation consists of three different production lines, the stainless-steel production line, the carbon-steel production line, and the assembly line. A detailed description of the three production lines can be found in Section 2.2.

The create a better understanding of what the simulation model looks like an overview of the data flow is created. the input data for the stainless-steel production line and the carbon-steel production line is represented in Figure 10.

Item	PartNo	Description	Qty	Material	Remark	Weight [kg]	Welding time	Stainless steelembly time...	certificate needed?	Carbon steel/stainleStain...
1	B0000-tek10-001	Single bracket small	3	AISI 304	3mm sheet	0.8	0	1	No	Stainless steel
2	B0000-tek10-002	Single bracket small	2	AISI 304	3mm sheet	1	0	1	No	Stainless steel
3	B0000-tek10-003	SoleNoid bracket	1	AISI 304	2mm sheet	0.4	0	1	No	Stainless steel
4	B0000-tek10-004	Bracket THt	1	AISI 304	4mm sheet	2.9	0	1	No	Stainless steel
5	B0000-tek10-005	GC wall support	1	AISI 304		3.4	5	2	No	Stainless steel
6	B0000-tek10-009	THT mopunting rail	2	AISI 304		4.1	0	1	No	Stainless steel
7	B0000-tek10-011	Bracket air pump	1	1.4301(AISI 304)		2.8	0	1	No	Stainless steel
8	B0000-tek10-015	Mounting sheet TT	1	1.4301(AISI 304)		0.4	0	1	No	Stainless steel
9	B0000-tek10-016	Mounting Sheet Junction Box	1	1.4301(AISI 304)		0.7	0	1	No	Stainless steel
10	B0000-tek10-017	Bracket LEL detection	2	1.4301(AISI 304)		0.4	0	1	No	Stainless steel
11	B0000-tek10-020	4G antenna wall support	1	AISI 304		6.8	5	2	No	Stainless steel
12	B0000-tek10-021	AStainless steelembly THT...	1			95.9	20	2	No	Stainless steel
	B0000-tek10-021-001	Weldment THT Storage	1	1.4307 (AISI 304L)		73	0	0	No	Stainless steel
	B0000-tek10-021-002	Weldment THT storage door	1	1.4307 (AISI 304L)		14.4	0	0	No	Stainless steel
	B0000-tek10-021-003	Weldment THT storage remo...	1	1.4307 (AISI 304L)		8.5	0	0	No	Stainless steel
13	B0000-tek10-022	Mounting sheet TT	1	1.4301 (AISI 304)		0.2	0	1	No	Stainless steel
14	B0000-tek10-023	Mounting bracket flow switch	1	AISI 304		0.2	0.5	1	No	Stainless steel
		Sheet	1	AISI 304	3mm sheet	0.1	160	120	No	Carbon steel
15	B0000-tek10-307	Weldment biogas upgrading...	1		40ft high cube	6338.2	0	0	Yes	Stainless steel
16	B0000-tek10-308	AStainless steelembly piping	1			1136.1	0	0	Yes	Stainless steel
	B0000-tek10-314	Piping biogas from compre...	1		0RHM10 / 0RHM12 / ORKL11	126.2	19	13.3	Yes	Stainless steel
	B0000-tek10-315	Piping retentate from sta...	1		0RKM10	43.9	32	22.4	Yes	Stainless steel
	B0000-tek10-316	Piping permeate from stac...	1		0RKC20	39.1	28	19.6	Yes	Stainless steel
	B0000-tek10-317	Piping permeate from stac...	1		0RKN10	35.6	26	18.2	Yes	Stainless steel
	B0000-tek10-318	Piping CO2 from stack 3	1		0RKC15	100.6	37	25.9	Yes	Stainless steel
	B0000-tek10-319	Piping reject	1		0RHM12	40.1	12	8.4	Yes	Stainless steel
	B0000-tek10-320	Piping CO2 blow off	1		0RKC15	16.4	5	3.5	No	Stainless steel
	B0000-tek10-321	Piping retentate from sta...	1		0RHM10	54.5	19	13.3	Yes	Stainless steel
	B0000-tek10-324	Piping retentate from sta...	1		0RKC10 / 0RKC20	84.9	25	17.5	Yes	Stainless steel
	B0000-tek10-325	Piping retentate from sta...	1		0RHH10 / 0RHH14	135.2	21	14.7	Yes	Stainless steel
	B0000-tek10-326	Piping safety blow off	1		0RHM13 / 0RHM15 / 0RKC30	37.3	28	19.6	No	Stainless steel
	B0000-tek10-327	Safety blow off	1		0RHM13	14.2	5	3.5	No	Stainless steel
	B0000-tek10-328	Piping biomethane to grid	1		0RHH10	21.4	9	6.3	Yes	Stainless steel
	B0000-tek10-329	Tubing gas inlet bypaStai...	1		ORHM11	1.5	3	2.1	Yes	Stainless steel
	B0000-tek10-330	Piping biomethane to grid...	1		ORHH10	30.2	6	4.2	Yes	Stainless steel
	B0000-tek10-331	Piping biogas compreStain...	1		0RHS20 / 0RKC20	34.8	9	6.3	No	Stainless steel
	B0000-tek10-332	Hose biogas from compreSt...	1		0RHM10	7.7	0	0	Yes	Stainless steel
	B0000-tek10-334	Piping chilld water inlet	1		0NDA10	14.4	4	2.8	No	Stainless steel
	B0000-tek10-335	Piping chilled water return	1		0NDB10	18	6	4.2	No	Stainless steel
	B0000-tek10-336	Piping biogas from compre...	1		0RHM10	7.1	2	1.4	Yes	Stainless steel
	B0000-tek10-337	Hose safety blow off comp...	1		0RHM15	7	0	3	No	Stainless steel
	B0000-tek10-338	Piping cold water inlet f...	1		0NDB20	40	9	7	No	Stainless steel

Figure 10 Input data

A sorter in the plant simulation sorts all sub-assemblies based on the information in the last column and pushes the sub-assemblies to either the carbon-steel or stainless-steel production line, as indicated in Figure 11.

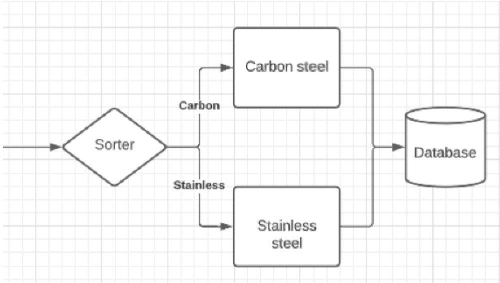


Figure 11 Sorter

When the sub-assemblies are sorted, they will either continue along the stainless-steel production line or the carbon-steel production line. An overview of the steps modelled with the stainless-steel production line and carbon-steel production line can be found in Figure 12.

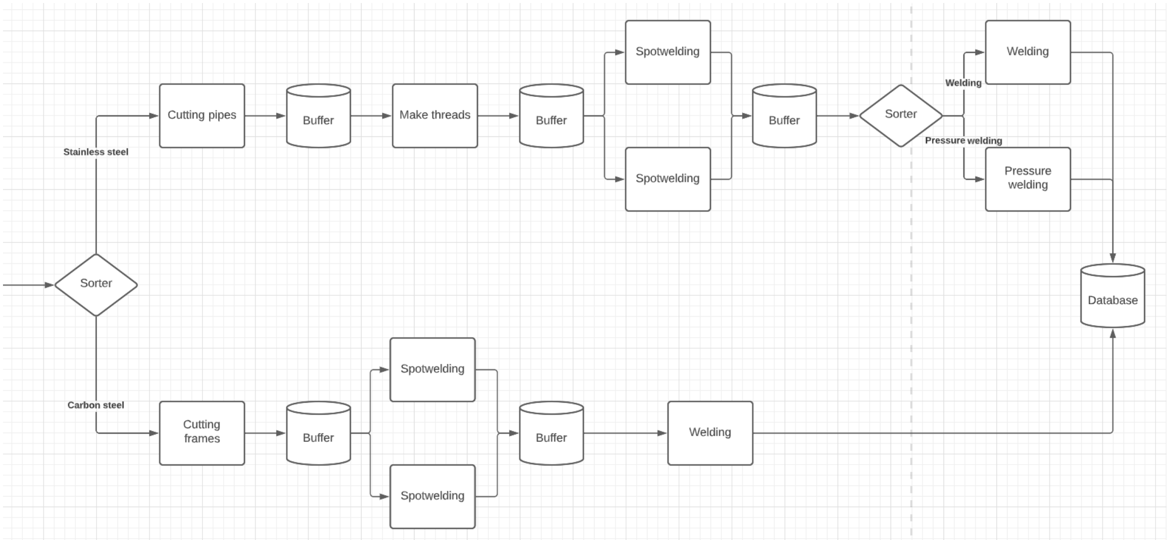


Figure 12 Stainless-steel and carbon-steel production line

Between each step of the production area, a buffer is created to store the WIP. This is done to create a more fluent production flow. This buffer is also available in the real production process. The database at the end of the production line keeps track of all the sub-assemblies that are created at the carbon-steel and stainless-steel production lines. This database is connected to steps 2 and 4 of the assembly line. The assembly line is displayed in Figure 13.

Within the new model, we want to make sure there are no idle times or large stocks built up within the carbon-steel and stainless-steel production lines. To realize this, a fluent production line must be created. A fluent production line can only be created after the 5S management technique is implemented since we will then be able to standardize the product process. We will then create a fluent production line by adding and subtracting workers for each step in the production line. If there are large fluctuations in the processing time of subassemblies, we can adapt the capacity of the WIP which will influence the idle time and therefore the workflow of the production line. Furthermore, we can investigate splitting up one sub-assembly into multiple sub-assemblies. We will change these parameters till a fluent production process is found.

In Figure 13 an assembly production line is represented. Within the production area of Instalsolutions, there are 6 spots at which such an assembly production line can be executed. Once a container is placed it is not moved anymore and the assembly teams of each step will walk to the container. There can be worked in 6 containers at the same time. In the current situation, there is only 1 team for each production process. For example, cutting-out frames can only be done in one container at the same time. Within the simulation, this is realised by adding worker stations to the workspaces and there is only 1 worker qualified to work at the workstation “Cut-out frame”.

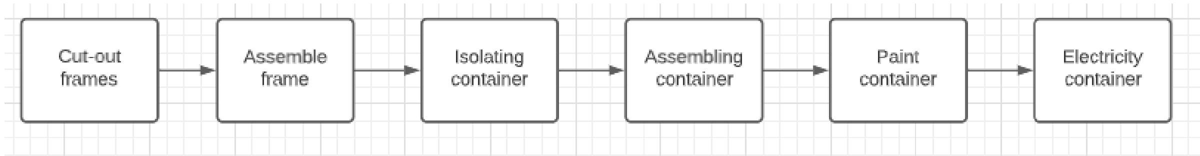


Figure 13 Assembly production line

All steps of the assembly production line are represented in Figure 4 in Section 2.2. Since not all steps are executed by Instalsolutions only the steps mentioned in Figure 13 will be modelled.

The fourth step of the assembly production line, insulating the container is currently done at instalsolutions by an external company. For this step, a station is implemented with a constant assembly time without any capacity constraint. Step six to step nine of the assembly production line is done by external companies or done outside the production area hence the assembly times are assumed to be fixed and the external companies do not have any capacity constraints. The container is finished for the production plant of Instalsolutions at step seven. Because of this, steps eight and nine are not relevant for the simulation and hence are outside the scope of this research.

Within the new model, we want to make sure there are no idle times or stocks built up within the assembly production line. To realize this, we start by optimizing the transfer between the electricity of the container and painting the container and work backwards. During this process, we want to create a fluent production line. We are adding or subtracting the number of available employees till a fluent production process is found.

In the new situation, we reduce the variability within the production process of Instalsolutions by making the production of sub-assemblies to stock. Since we switch from MTO production process to MTS production process and all buy-in products are directly delivered to Instalsolutions we expect additional storage space must be created within the warehouse of Instalsolutions. Because of this, we will look at rearranging the warehouse in Section 4.3.

4.3 Redesigned warehouse of Instalsolutions

In Section 3.3 we gained knowledge regarding the safety rule which must apply within a warehouse and how we can optimize the storage space of Instalsolutions. In this section, we will use this acquired knowledge to come up with a warehouse layout which maximized the storage space. More storage space is needed for two reasons, firstly, in the current situation, a lot of buy-in products for Instalsolutions are first delivered at the warehouse in the Netherlands. Here the products are repacked per project and shipped to Poland. HoSt bioenergy systems wants the buy-in products directly delivered to Poland on short notice. Secondly, Instalsolutions will start producing sub-assemblies on stock, so storage space must be created to store the sub-assemblies.

When designing a warehouse structure one of the first things that must be decided is the warehouse layout. The three most basic warehouse layouts are the U-shaped warehouse, L-shaped warehouse, and I-shaped warehouse. A general overview of the different types of warehouses can be found in Figure 14. (warehouse-setup-guide, 2021)

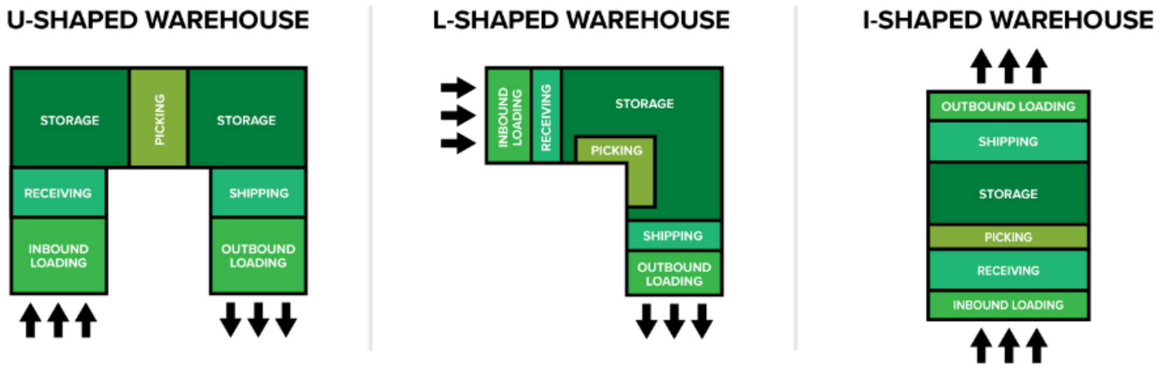


Figure 14 Warehouse layouts

(warehouse-setup-guide, 2021)

Since the warehouse of Instalsolutions only has one door at which trucks can load and unload, we decided a U-Shaped warehouse structure will be applied and both the inbound and outbound loading will go through the available door. Since Instalsolutions only receives around 10 shipments per week and sends 2 or 3 shipments per week no problems are expected in the in-/outbound loading area. An important benefit of the U-shaped warehouse structure is that the utilization of resources such as personnel and handling equipment such as forklift trucks can be shared. The last benefit of the U-shaped warehouse structure for Instalsolutions is that the in-/outbound loading and receiving/shipping can be done in front of the storage area. In front of the storage area there is enough space to set up a tent in which the in-/outbound and receiving/shipping can be done. Because the in-/outbound loading and receiving/shipping can be done outside the storage area there will be more space available to store products.

When designing the warehouse layout at Instalsolutions there are two warehouse types which must be taken into consideration. The first warehouse will be referred to as “tent” and the second warehouse will be referred to as “warehouse”.

The first warehouse we focus on is the tent outside the production area of Instalsolutions. In this area, all smaller buy-in products are stored. Inside the tent cannot be reached with a forklift truck and all products must be picked up by hand. The current racks and measurements of the tent can be found in Figure 8 in Section 2.3.

Based on an interview with the person who designed the warehouse at HoSt bioenergy systems in the Netherlands we concluded that the same measurements as in the Netherlands can be applied at Instalsolutions as well. Hence the aisle should have at least a width of 75 cm. Furthermore, the height of the racks should not exceed a height of two meters otherwise the racks must be linked to each other or the building since the ratio of the height and depth exceeds 4:1 (Stichting Arbo en Podiumkunsten, 2007; Verduijn, 2022).

We will now focus on the optimization of the big warehouse on the right side of the production area. In the warehouse, all larger products will be stored, and each article must be reachable with the forklift truck. The current racks and measurements of the warehouse can be found in Figure 7 in Section 2.3.

The goal is to find to optimize the available racking space within the warehouse since we do not know how much space we exact need. Based on the fact that all products must be directly delivered to Poland instead of first to the Netherlands and in Section 4.2 of this research we investigate the possibility of making sub-assemblies to stock we expect additional warehouse space must be created. To create as much racking space as possible we investigated what height racks are allowed. As mentioned in Section 3.3 the height of the racks inside a warehouse is determined by the clearance of the sprinkler heads. There must be a clearance of at least 50 cm. Because of this, the racks with a height of 488 cm can be placed inside the warehouse and one more pallet can be placed on top of the racks. The standard height for each pallet + beam = 148 cm. For this reason, at all places within the warehouse, the racks can fit 5 pallets above each other.

The pallets used at Instalsolutions are the basic pallets which a measurement of 121.92 x 101.6 cm. To determine how much space must be reserved for a pallet we investigate the way pallets are placed in warehouse racks. When designing a warehouse layout there are different measurements which must be considered when a single rack or double rack is placed inside a warehouse. When a single rack is placed inside a warehouse it is beneficial that the pallet has an overhang of 3 inches at both sides, as can be seen in Figure 15. This is caused by the fact that this helps to distribute the weight equally over a beam instead of the wire decking between the beams. Furthermore, the pallet can be more easily picked up by a forklift truck. When a double rack is placed inside a warehouse there are two different ways to place the pallet. The first way is pictured in Figure 15. The second way to place the rack is indicated in Figure 16. The benefits mentioned above apply to this second warehouse racking system hence this one is advised.

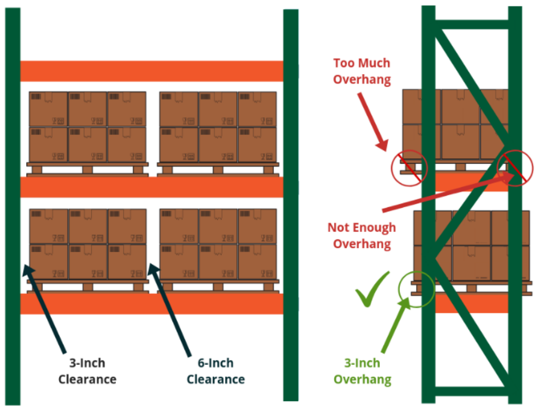


Figure 15 Racking system

(Brittany Jones, 2022)

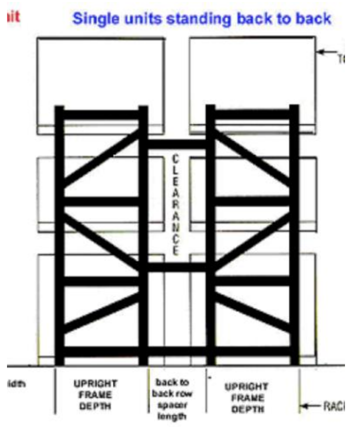


Figure 16 Racking system 2

(SJF.com, 2022)

This information is added not because it contrasts with the current situation but because it includes safety measurements, which we think is important to mention. Furthermore, the space between a double rack and the overhang is important to consider when we decide if an additional rack can be placed within the warehouse or not.

The width of the aisles needed in a warehouse is determined by the type of forklift truck available at the company. At Instalsolutions there are currently three forklift trucks available. The aisle length and turning cycle needed for each forklift truck are mentioned in Table 3.

Type	Aisle	Turning cycle
Linde H50	4653 mm	2743 mm
Linde H40	4720 mm	2785 mm
JCB TLT 30d	4710 mm	2997 mm

(JCB Headquarters Savannah, 2000; Motrac, 2022)

Table 3 Forklift trucks of Instalsolutions

The aisle width needed for the forklift trucks available at Instalsolutions is relatively high. Because of this we looked into forklift trucks or reach trucks which need a smaller aisle width. We came up with the 9700 Swing-Reach turret truck. The reach truck can be outfitted to accommodate a wide range of aisle widths and oversized loads – up to 122 cm deep and 275 cm wide, in aisles as narrow as 167.64 cm (raymondcorp, 2022). This reduces the aisle width needed by almost three meters. In Section 5.3 we will compare different warehouse layouts based on the forklift truck used and the warehouse space needed.

4.4 The simulation model

In this section, we will discuss the data used in the simulation model. Based on the available data we decided on the settings of the simulation.

The data available are the production times of one 10-300 which are represented in Table 4 and Table 5. The welding time mentioned is the time needed by the stainless-steel and carbon-steel production line to make the sub-assemblies. The assembly time is the time needed in step two and step four of the assembly production line to assemble the sub-assemblies on the container. Because of this, the carbon-steel sub-assemblies must be finished before the second step of the assembly production line and the stainless-steel sub-assemblies must be finished before the fourth step of the assembly line.

Department	Welding time (in hours)	Assembly time (in hours)
Carbon-steel	224	143
Stainless-steel	357	266.2
Total	581	409.2

Table 4 Welding and assembly times for 10-300

The production time of the assembly stations are represented in Table 5:

Step:	Name	Time needed (in hours):
Step 1	Cut-out frames	120
Step 2	Assemble carbon-steel assemblies	143
Step 3	insulation	120
Step 4	Assembly stainless-steel assemblies	266.2
Step 5	Painting	120
Step 6	Electricity	210

Table 5 Production times assembly stations

In the way the data is presented above it seems like the sub-assemblies in carbon-steel and stainless-steel production lines will not be finished on time, but this cannot be said with any certainty. The available data only provides us with the total production time of each sub-assembly of a 10-300 and the data is not split-up in the different working stations as mentioned in Figure 5 and Figure 6. The different working stations in Figure 5 and Figure 6 can work simultaneously. Theoretically, this could mean the time needed to make all sub-assembly of the stainless-steel production line could be only 59.5 hours. The time needed for all sub-assemblies of the carbon steel production line could theoretically be only 56 hours. Because of this, we assume the carbon-steel and stainless-steel sub-assemblies will always be finished before step two and step four of the assembly production line. But if it turns out the capacity of the different stations of the stainless-steel production line or carbon-steel production line are close to each other, and we are dealing with high variation between the different sub-assemblies it will be beneficial to start production to stock and increase the WIP capacity. For this reason, we created a simulation model in which the data can easily be adapted by Instalsolutions when more data comes available. In Appendix A we made an Instruction video on how Instalsolutions can fill in the input data and retrieve the results of the simulation.

We will now have a closer look at the assembly production line. The available information is the hours needed per station at each assembly station. The production steps Painting and Electricity are not done within the production hall of Instalsolutions hence, there will be no capacity constraint for these stations within the model. The Insulation step is done by an external company and 5 working days are allowed by Instalsolutions. For steps 1 to 4, there are six available spots within the production hall of Instalsolutions. To calculate how many spots should be reserved for which step of the production station we minimized the throughput and maximize the output we found the following division of spots.

Step:	Name	Time needed (in hours):	Spots:	Throughput time
Step 1	Cut-out frames	120	1	120 hours
Step 2	Assemble carbon-steel assemblies	143	2	71.5 hours
Step 3	Insulation	120	1	120 hours
Step 4	Assembly stainless-steel assemblies	266.2	2	133.1 hours
Step 5	Painting	120	1	120 hours
Step 6	Electricity	210	2	105 hours

Table 6 Assembly line lay-out

There is no data available on how many employees can work at the different steps of the production line, in other words with how many people the 120 hours of Cutting frames can be finished. Because of this, we assumed only one person is working at each station within the simulation.

4.5 Conclusion

In this chapter, we applied the gained knowledge from chapter 3 to Instalsolutions. In Section 4.1 we discussed how the 5S management can be implemented at instalsolutions and how we will take this into account when we set up the working structure. Furthermore, we explain how the working structure will help to gather necessary data. Section 4.2 explains how we created a simulation model which represents the current production process of Instalsolutions and how the model will be adapted to a delayed differentiation production process. Section 4.3 expressed how the safety rules and space optimization will be applied within the warehouse of Instalsolutions. Lastly, in Section 4.4 the data used in the simulation model and the settings of the simulation based on the available data are discussed.

5. Results

In this chapter, the results of our deliverables will be discussed. In Section 5.1 the work structure is provided. In Section 5.2 the outcome of the simulation model is discussed. Lastly, the results of the warehouse layouts are discussed in Section 5.3

5.1 Results of the work structure of Instalsolutions

In Section 4.1 we discussed the benefits of the created working structure based on the 5S management technique. In this section, the result of the working structure will be provided.

After HoSt bioenergy systems brought a majority stake to Instalsolutions the focus of Instalsolutions is on the production of four different products, these products will be referred to as the 10-100, 10-300, 10-500 and 10-600. Each of these final products can be further specified in approximately 50 sub-assemblies. Of these 50 sub-assemblies, approximately 15 sub-assemblies are the same for each of the four products, the other 35 sub-assemblies are product specific. The sub-assemblies either consist of more sub-assemblies or strictly buy-in products. To create more consistency within the production process of Instalsolutions for each final product an overview of all sub-assemblies is created. In Figure 17 a subsection of the total overview is represented.

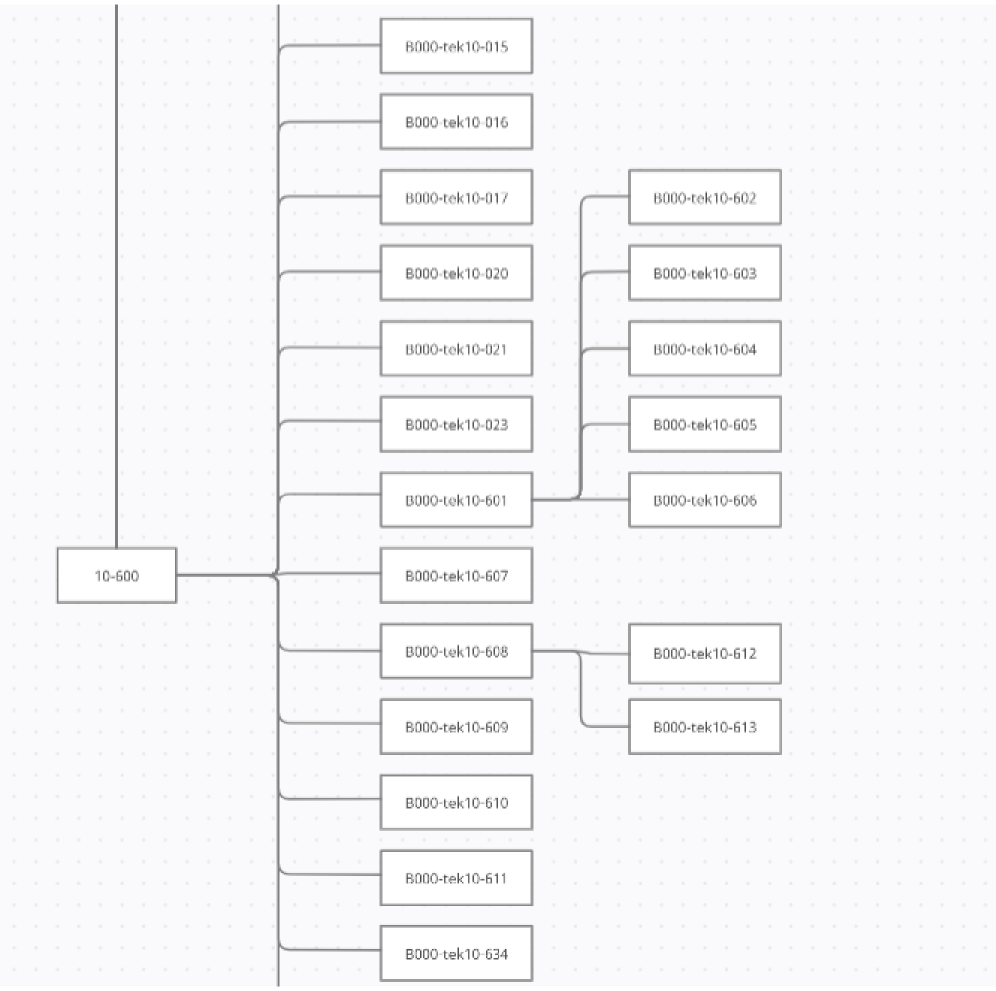


Figure 17 Overview sub-assemblies

Figure 17 creates an overview of what sub-assemblies must be produced to create a 10-600. If we click on one of the sub-assemblies a new screen opens which represents the working structure for the specific sub-assembly. The working structure for the B0000-tek10-005 is represented in Figure

18 and Figure 19. This creates more structure within the production process of Instalsolutions and we expect the variation within the production time of the sub-assemblies will decrease. Furthermore, this creates a clear overview of what sub-assemblies are needed for each product and hence helps to create insight into whether a project will be finished on time or not.

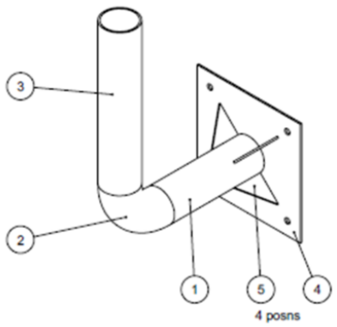
B0000-tek10-005

Part. No:
Order No:

Title:
Dossier title:

Time needed:
Dossier type:

Certificates needed:



PartNo	Description	Qty	Type or dimension	Length	Material	Remark	Weight [kg]
	Pipe	**1**	**Ø60,3 x 2,9**	**174**	**AISI 304**		**0,7**
	Elbow	**1**	**Ø60,3 x 2,9 EN 10253-4 Type A**	**119.4**	**AISI 304**		**0,5**
	Pipe	**1**	**Ø60,3 x 2,9**	**274**	**AISI 304**		**1,1**
	Sheet t=3mm	**1**	**200 x 200**		**AISI 304**		**1**
	Sheet t=3mm	**4**	**50 x 50**		**AISI 304**		**0**

Work structure:

1. Get parts needed
2. Measure everything
3. Start weld image 1
4. Start weld image 2
5. Start weld image 3
6. Start weld image 4
7. Place sub-assembly in stock
8. Check of to-do list

Equipement :

1. Ruler
2. Welding machine
3. Welding goggles
4.

Figure 18 Example working structure B0000-tek10-005

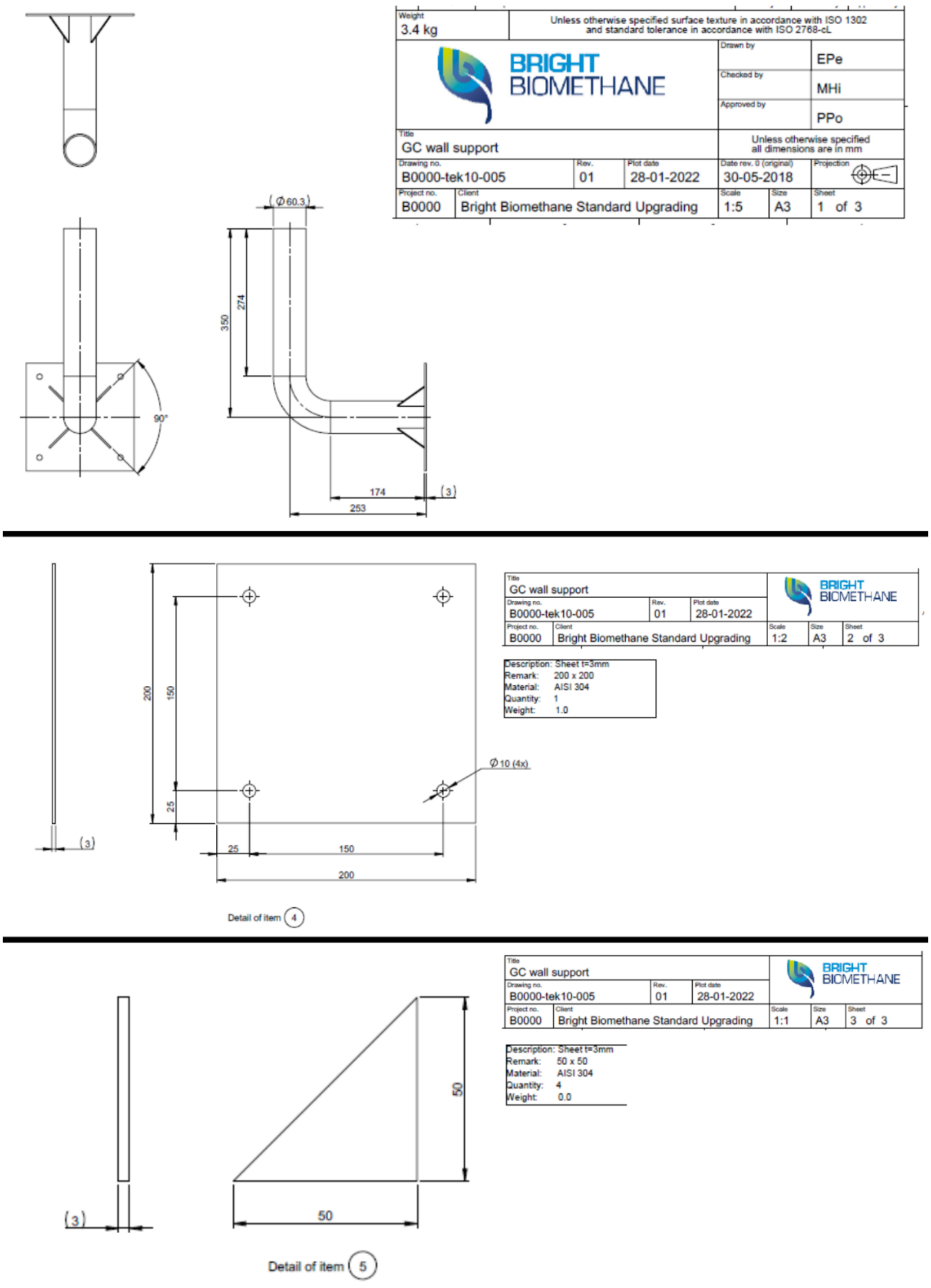


Figure 19 Production drawings B0000-tek10-005

The working structure provides a clear step-by-step approach for each sub-assembly. This step-by-step approach provides Instalsolutions with more structure within the production process of Instalsolutions and we expect the variation within the production time of the sub-assemblies will decrease. Furthermore, it provides Instalsolutions with insights into which data is relevant and must be collected. Because of this, it should be easier to gather information regarding the production time of each sub-assembly. The data gathered will be used in this research's second and third deliverables.

5.2 The outcome of the simulation model

The first goal of our simulation was to create insight into the two different production processes. First, is the current production process, in which the whole production process is modelled as an MTO production line. In the second model, the carbon-steel and stainless-steel production line start production as MTS which creates the delaying differentiation production process. The goal of the simulation was to figure out how much Instalsolutions benefits from this change and find possible bottlenecks within the assembly procedure.

The second goal of our simulation was to optimize the carbon-steel and stainless-steel production lines. In our simulation, each step of the production process is specified, in this way we wanted to find out in which step the WIP piled up and look at the consequences of increasing the buffer size further we can see the influence of adding employees at certain states. The only available data regarding the production time of the carbon-steel and stainless-steel production lines are regarding the same 10-300. The available data is not specified per station but given as a total for the whole production line. For this reason, we created a simulation model in which the data can easily be adapted by Instalsolutions when more data comes available. In Appendix A we made an Instruction video on how Instalsolutions can fill in the input data and retrieve the results of the simulation.

Based on the available data we created the most efficient workflow by adding and subtracting employees at a certain station, as stated in Section 4.4. When we put this data into our simulation model we ended up with a total throughput rate of 0.16 products per day. We calculated the average idle time per station which is represented in Table 7.

Station:	Average idle time employees:
Cut-out frames	0%
Assemble carbon-steel assemblies	41.36%
Insulation (external company)	3%
Assembly stainless-steel assemblies	5.05%

Table 7 Average idle time per station

Based on this information the current production of Instalsolutions is maximized since all employees have high working times except the employees who are working on the assembly of carbon-steel assemblies. In our model there are currently working two people working parallel at this step, if we would run the simulation again 1 person should have a working time of 117.28% of the time to get the same throughput rate, which is not possible. Because of this, we found the most optimal division of the production process based on the information available.

Now we found the most efficient working flow possible we can look at a possible bottleneck within the production process of Instalsolutions. In Figure 20 we present the start and end time of each station of the assembly production line of the first 35 biogas upgrading systems produced.

Number of containers	Start cut frame	Finish cut frame	Start assemble frame	Finish assemble frame	Start insulating	Finish insulating	Start assemble pipes	Finish assemble pipes	Start painting	Finish painting	Start electricity	Finish electricity
1	0.00	5.00	5.00	7.98	7.98	12.98	12.98	24.07	24.07	29.07	29.07	33.45
2	5.00	10.00	10.00	12.98	12.98	17.98	17.98	29.07	29.07	34.07	34.07	38.45
3	10.00	15.00	15.00	17.98	17.98	22.98	24.07	35.16	35.16	40.16	40.16	44.54
4	15.00	20.00	20.00	22.98	22.98	27.98	29.07	40.16	40.16	45.16	45.16	49.54
5	20.00	25.00	25.00	27.98	27.98	32.98	35.16	46.25	46.25	51.25	51.25	55.63
6	25.00	30.00	30.00	32.98	32.98	37.98	40.16	51.25	51.25	56.25	56.25	60.63
7	30.00	35.00	35.00	37.98	37.98	42.98	46.25	57.35	57.35	62.35	62.35	66.72
8	35.00	40.00	40.00	42.98	42.98	47.98	51.25	62.35	62.35	67.35	67.35	71.72
9	40.00	45.00	45.00	47.98	47.98	52.98	57.35	68.44	68.44	73.44	73.44	77.81
10	45.00	50.00	50.00	52.98	52.98	57.98	62.35	73.44	73.44	78.44	78.44	82.81
11	50.00	55.00	55.00	57.98	57.98	62.98	68.44	79.53	79.53	84.53	84.53	88.90
12	55.00	60.00	60.00	62.98	62.98	67.98	73.44	84.53	84.53	89.53	89.53	93.90
13	60.00	65.00	65.00	67.98	67.98	72.98	79.53	90.62	90.62	95.62	95.62	100.00
14	65.00	70.00	70.00	72.98	72.98	77.98	84.53	95.62	95.62	100.62	100.62	105.00
15	70.00	75.00	75.00	77.98	77.98	82.98	90.62	101.71	101.71	106.71	106.71	111.09
16	75.00	80.00	80.00	82.98	82.98	87.98	95.62	106.71	106.71	111.71	111.71	116.09
17	80.00	85.00	85.00	87.98	87.98	92.98	101.71	112.80	112.80	117.80	117.80	122.18
18	85.00	90.00	90.00	92.98	92.98	97.98	106.71	117.80	117.80	122.80	122.80	127.18
19	90.62	95.62	95.62	98.60	98.60	103.60	112.80	123.90	123.90	128.90	128.90	133.27
20	95.62	100.62	100.62	103.60	103.60	108.60	117.80	128.90	128.90	133.90	133.90	138.27
21	101.71	106.71	106.71	109.69	109.69	114.69	123.90	134.99	134.99	139.99	139.99	144.36
22	106.71	111.71	111.71	114.69	114.69	119.69	128.90	139.99	139.99	144.99	144.99	149.36
23	112.80	117.80	117.80	120.78	120.78	125.78	134.99	146.08	146.08	151.08	151.08	155.45
24	117.80	122.80	122.80	125.78	125.78	130.78	139.99	151.08	151.08	156.08	156.08	160.45
25	123.90	128.90	128.90	131.88	131.88	136.88	146.08	157.17	157.17	162.17	162.17	166.55
26	128.90	133.90	133.90	136.88	136.88	141.88	151.08	162.17	162.17	167.17	167.17	171.55
27	134.99	139.99	139.99	142.97	142.97	147.97	157.17	168.26	168.26	173.26	173.26	177.64
28	139.99	144.99	144.99	147.97	147.97	152.97	162.17	173.26	173.26	178.26	178.26	182.64
29	146.08	151.08	151.08	154.06	154.06	159.06	168.26	179.35	179.35	184.35	184.35	188.73
30	151.08	156.08	156.08	159.06	159.06	164.06	173.26	184.35	184.35	189.35	189.35	193.73
31	157.17	162.17	162.17	165.15	165.15	170.15	179.35	190.45	190.45	195.45	195.45	199.82
32	162.17	167.17	167.17	170.15	170.15	175.15	184.35	195.45	195.45	200.45	200.45	204.82
33	168.26	173.26	173.26	176.24	176.24	181.24	190.45	201.54	201.54	206.54	206.54	210.91
34	173.26	178.26	178.26	181.24	181.24	186.24	195.45	206.54	206.54	211.54	211.54	215.91
35	179.35	184.35	184.35	187.33	187.33	192.33	201.54	212.63	212.63	217.63	217.63	222.00

Figure 20 Deterministic throughput times assembly line in days

In Figure 20 we can easily see that work will pile up in front of step four, the assembly of stainless steel pipes. Within Figure 20 we only took deterministic data into account, so this problem will expand rapidly when we take the variation within the production process into account. The table also provides the information that after the production of 18 containers the cut-out frames department cannot start working on the next container since all spots are occupied or waiting in line for the assembly of stainless steel. This shows that the bottleneck within the production process of Instalsolutions is in front of step four of the assembly production line.

In Figure 20 we can see it will take 117.80 days to start the assembly of piping on the 20th container. If no steps in the stainless-steel production line can be done simultaneously, we will need 20 x 357 hours = 7140 hours = 297.5 days to prepare all sub-assemblies. Based on the employees of Instalsolutions this is not the case, and all sub-assemblies are ready before step four of the assembly line. We can do the same calculation for the carbon-steel sub-assemblies. The assembly of the carbon-steel sub-assemblies for the 20th container can start at day 100.62. If no steps of the carbon-steel production line can be done simultaneously the sub-assemblies are available after 20 x 224 = 4480 hours = 186.67 days. The employees assure that the sub-assemblies of the carbon-steel department are finished before the start of step two of the assembly production line.

5.3 Possible warehouse layout for Instalsolutions

In Section 4.3 we applied the safety rules to Instalsolutions and investigated additional information and possibilities to optimize the warehouse space to Instalsolutions. In this section, we will discuss the warehouse layouts we came up with.

We will first optimize the tent warehouse of Instalsolutions. At the door of the tent, we left an open area so that in case of rain two pallets can be placed inside and prepared for shipping inside. Furthermore, the safety beams are indicated as dots on the drawing.

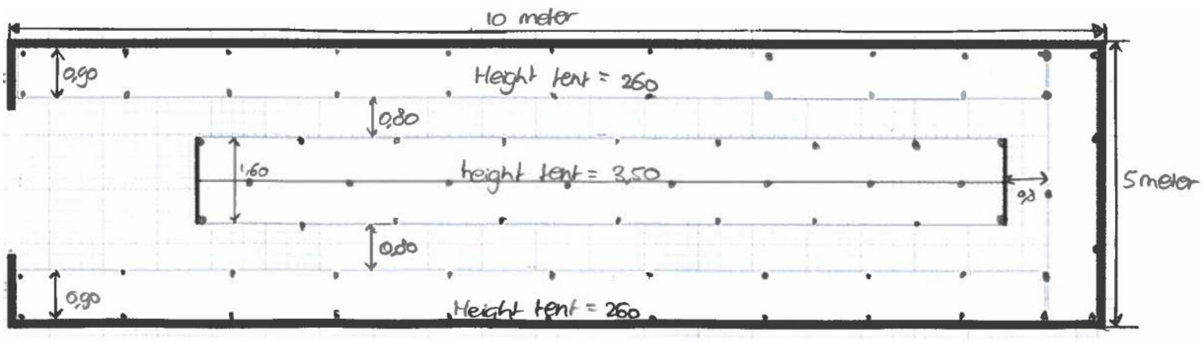


Figure 21 Layout tent

When we do not change the number of shelves in each rack, we have created a storage space of 188.1 square meters in total. In the current situation, there is a total storage space of 94.1 square meters, hence this is an improvement of 99.9 per cent.

We will now have a look at the layout of the big warehouse on the right side of the production area. When we optimize the storage space based on the forklift trucks available at Instalsolutions the best achievable warehouse layout is represented in Figure 22. Each number indicates a standardized pallet place. The safety beams are indicated as dots on the drawing.

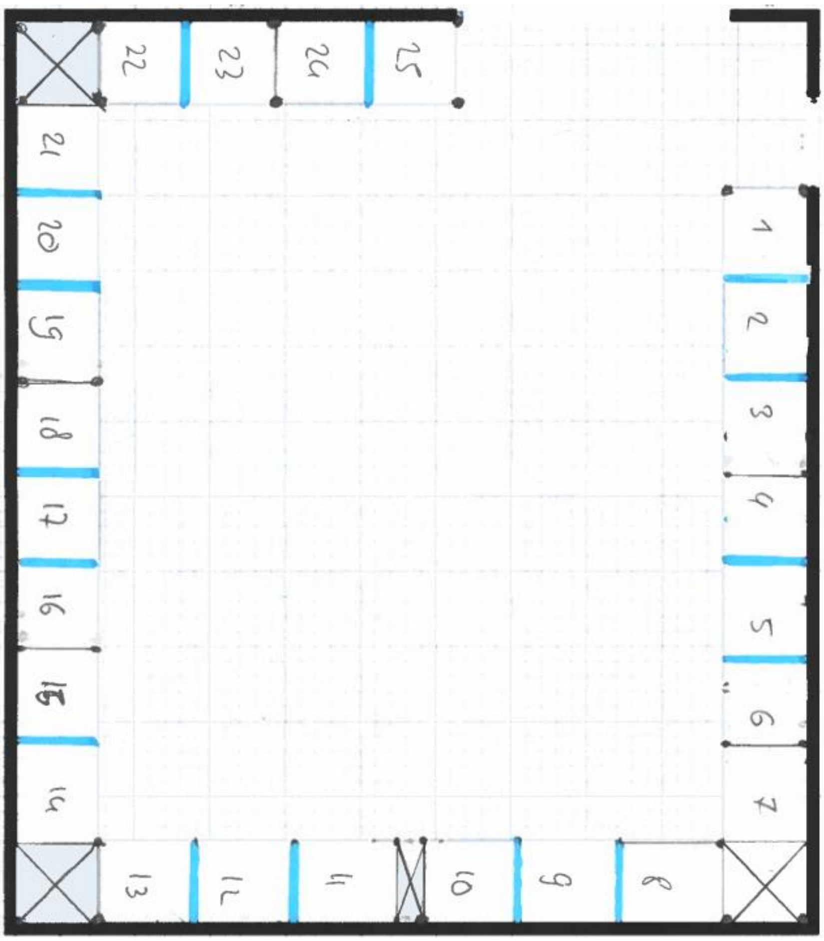


Figure 22 Layout warehouse Instalsolutions forklift truck

This solution creates space for 125 pallets, this is an improvement of 25% of the storage space compared to the current warehouse layout of Instalsolutions.

To check whether this warehouse layout seems reasonable we apply the calculation regarding optimizing the storage space as mentioned in Section 3.3. The total available space = 10.5 * 12 = 126 square meter. The space reserved for pallets = 25 pallets * 1.22 per pallet = 30.5 square meter. $\frac{30.5}{126} * 100\% = 24.2\%$. This is in line with the paper, which concludes a storage space between 22% and 27%.

Since a lot of space is lost because of the large aisle width of the forklift truck, we found out a lot smaller aisle length is needed when a reach turret truck is used. In the next warehouse layouts, we will take the 9700 Swing-Reach turret truck into account which needs an aisle width of 167.64 cm (raymondcorp, 2022). We place as many racks inside the warehouse as possible and came up with the layout depicted in Figure 23.

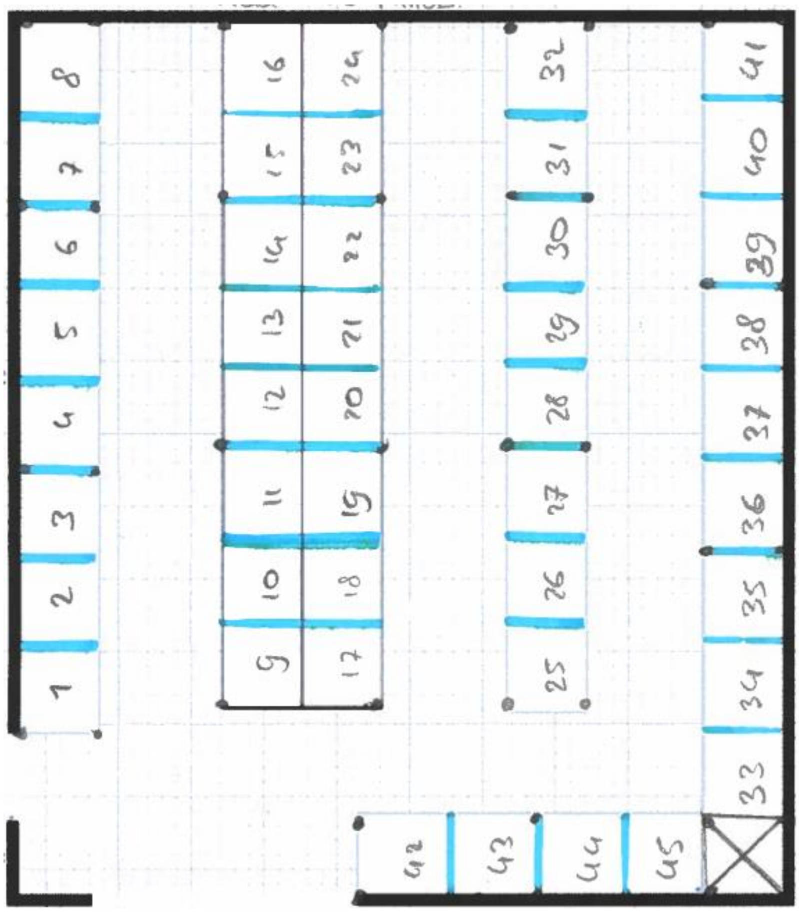


Figure 23 Best possible warehouse layout Instalsolutions turret truck

This layout creates a total of 225 pallet places; hence this is an improvement of 125% compared to the current situation.

In this warehouse layout, the turret truck has a clearance of two to three cm on both sides. This might not be desirable since this asks a lot from the turret truck driver. Because of this, we decided to make two other warehouse layouts which are indicated in Figure 24 and Figure 25. In the layout depicted in Figure 24, we created some storage space for small products which are currently stored inside the additional tent warehouse outside the production area.

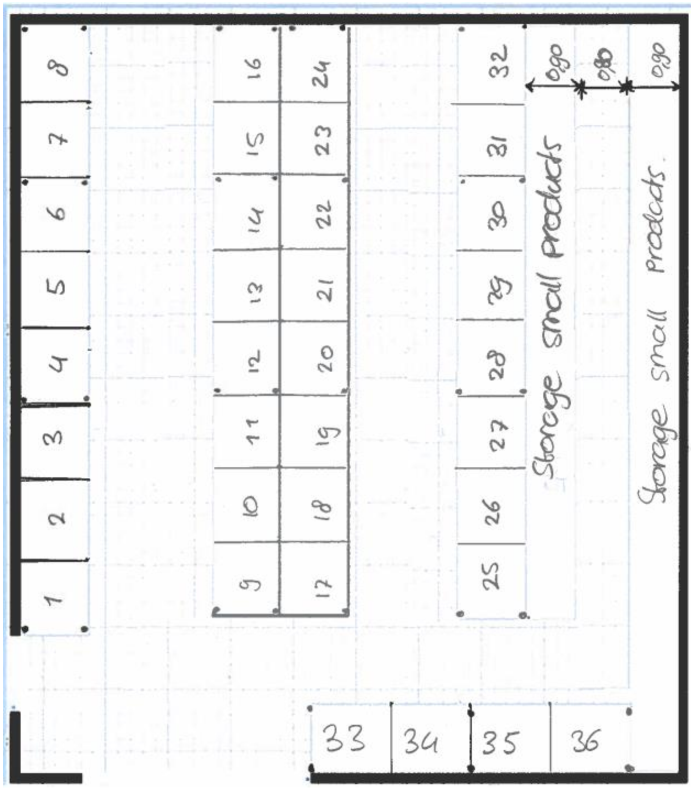


Figure 24 Option 1 warehouse layout turret truck

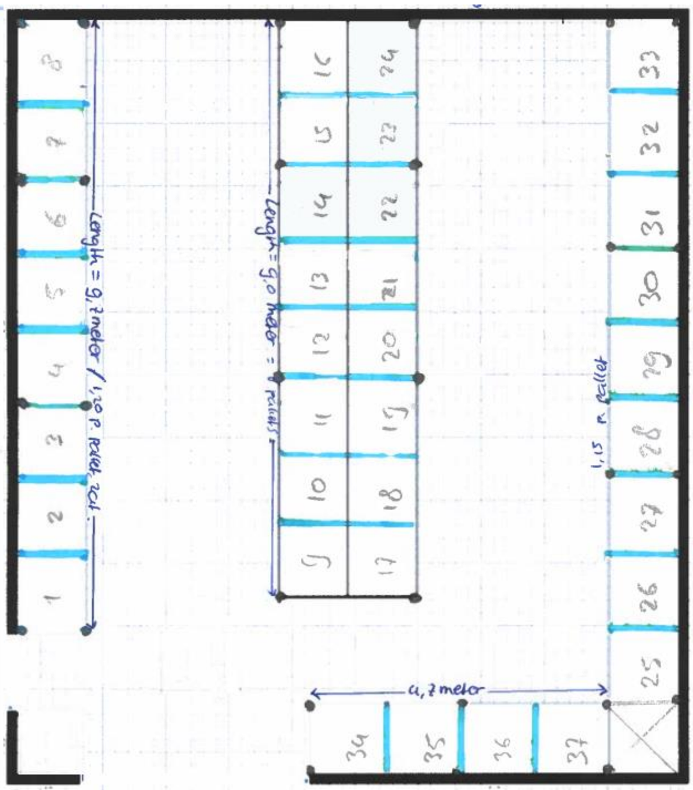


Figure 25 Option 2 warehouse layout turret truck

In Figure 24 a total of 180 pallet places are created and approximately 68 square meters of storage for small products are created. If we only consider the improvement of pallets is already an improvement of 85%.

In Figure 25 a total of 185 pallet places are created. This is compared to the current situation an improvement of 80%.

There is not yet enough data available to determine the total storage space needed, because of this we could not yet select the best suitable warehouse layout for Instalsolutions. Because of this we came up with multiple warehouse layouts and determined the storage space available in each layout. In this way, Instalsolutions can easily decide when the total storage space needed is determined. Furthermore, we would like to advise Instalsolutions on which product should be stored at which location. Unfortunately, the necessary data is not available yet, which made it impossible to decide the location of all buy-in products and sub-assemblies.

5.4 Conclusion

In this chapter, the results of the research are discussed. In Section 5.1 we provide Instalsolutions with the working structure created. The working structure will improve the quality of the products of Instalsolutions. Furthermore, the working structure will create more structure within the production process which will help Instalsolutions to gather the necessary data. In Section 5.2 the bottleneck of the production process of Instalsolutions is found and the results of the simulation model are presented. Section 5.3 provides instalsolutions with multiple solutions to generate more storage space within the warehouse. We recommend different warehouse solutions based on the current forklift trucks available and when a reach truck is bought by Instalsolutions.

6. Conclusion, recommendation, discussion, future research

This chapter is split into four sections. Section 6.1 states the conclusion of this research. Section 6.2 mentions the recommendations for HoSt bioenergy systems based on the outcomes of this research. In Section 6.3 the discussion of the research is stated. In this discussion, we pay to the assumptions and limitations in this research and their impact on the outcomes of this research. Section 6.4 states which parts of the research could be further analysed.

6.1 Conclusion

This section is divided into four sub-sections. In the first sub-section, the conclusion regarding the working structure of Instalsolutions is discussed. In the second sub-section, the conclusion on the production process is provided. Thirdly we will discuss the conclusion on the warehouse layout. Lastly, a general conclusion is provided.

6.1.1 Conclusion working structure

In the first deliverable, a working structure was provided to Instalsolutions. The working structure will standardize the production process of Instalsolutions, which will improve the quality of the products. Furthermore, the working structure will help instalsolutions to have a clear overview of the production process and to keep the workspace clean. The time spent on seeking necessary things will reduce and the safety level will increase. Furthermore, industrial pollution will decrease, and employee motivation will increase. The working structure makes it easier to gather the necessary data and a decrease in the variability of the production times will be realized. Furthermore, the groundwork for implementing the 5S management technique is pointed out which has many benefits such as:

- A decrease in the variability of the production times of sub-assemblies (Patel & Thakkar, 2014).
- Create more insight into whether a project will be finished on time or not (Patel & Thakkar, 2014).
- Increasing the efficiency of all processes sustained by a reduction in search time (Kuchekar et al., 2019).
- Minimization or even elimination of losses in the company (Grupta, 2021).
- Smoother process flow within the production process (Costa et al., 2018).
- The quality control will be increased (Subburaman, 2019).
- The safety and security of the working space will be increased (Subburaman, 2019).

Based on the literature research the benefits of the 5S methods differ a lot based on the starting point of the company and the way of implementation in the company. Based on observations made and conversations with employees of Instalsolutions we expect the implementation of the working structure will be beneficial.

6.1.2 Conclusion production process

Within the second deliverable, we have created insights and understanding into the production process of Instalsolutions and made visible which data must be collected. Based on the available data we have found how Instalsolutions should distribute the workforce to create the most optimal workflow within the production process of Instalsolutions. Based on this optimal workflow the idle times per station and the throughput rate of the production process are given. Furthermore, the bottleneck within the production process is found. Lastly, we have provided instalsolutions with a simplified simulation model and tutorial so Instalsolution can easily fill in the more specified data.

6.1.3 Conclusion warehouse layout

In the third deliverable, we provided Instalsolutions with multiple solutions to generate more storage space within the current warehouse of Instalsolutions. To achieve this, we investigated which safety rules must apply within a warehouse to create a safe work environment. Once we created an overview of all safety rules which must be met, we looked into literature to optimize the warehouse space. We recommend different warehouse solutions based on the current forklift trucks available and when a reach truck is bought by Instalsolutions. The data to make a product-specific warehouse layout was not available nor was the data to determine the amount of storage space needed. Because of this, we expressed the amount of storage space created in standard pallets.

Once the data needed is gathered by Instalsolutions the storage space needed to store all necessary products can be calculated. Based on the storage space needed the best suitable warehouse layout for Instalsolutions can be selected from the layouts provided in this research. Instalsolutions can create a product-specific warehouse layout which will reduce the search time for products and many more benefits, such as increasing the employee's motivation, increasing the efficiency of the employee and increasing the production rate.

6.1.4 General conclusion

We created a step-by-step working structure for Instalsolutions which will improve the quality of the products. Furthermore, the working structure will help instalsolutions to have a clear overview of the production process and to keep the workspace clean. The time spent on seeking necessary things will reduce and the safety level will increase. Furthermore, industrial pollution will decrease, employee motivation will increase, and more structure is provided to help gather the necessary data.

We created insights and understanding in the production process of Instalsolutions and made visible which data must be collected. Furthermore, we decided how Instalsolutions should distribute the workforce to create the most optimal workflow within the production process of Instalsolutions. The most optimal workflow will increase the production rate of Instalsolutions. Based on this optimal workflow the idle times per station and the throughput rate of the production process are given. Furthermore, the bottleneck within the production process is found. Lastly, we have provided instalsolutions with a simplified simulation model and tutorial so Instalsolution can easily fill in the more specified data.

The last deliverable provides instalsolutions multiple solutions to generate more storage space within the warehouse. We recommend different warehouse solutions based on the current forklift trucks available and when a reach truck is bought by Instalsolutions. Instalsolutions can choose which warehouse layout to implement once the data is gathered to decide the total storage space needed.

In general, we were able to create transparency and insight into the current production process of Instalsolutions. This research points out how to optimize the production area by implementing the 5S management strategy which will decrease the variability and increase the production rate of Instalsolutions. Furthermore, these insights will make the production process more predictable which will make the forecast for the purchasing department easier. Secondly, we created insights and understanding in the production process of Instalsolutions and made visible which data must be collected. Furthermore, we provided instalsolutions with an overview of how to distribute the workforce to create the most optimal workflow within the production process of Instalsolutions. Based on this optimal workflow the idle times per station and the throughput rate of the production process are given. We have found the bottleneck within the production process is found. Lastly, we suggest multiple solutions to increase storage space within the warehouses. This will help HoSt bioenergy systems and Instalsolutions to directly deliver all buy-in products to Instalsolutions.

6.2 Recommendation

This section is divided into four sub-sections. In the first sub-section, the recommendations regarding the working structure of Instalsolutions are discussed. In the second sub-section, recommendations on the production process are provided. Thirdly some recommendations regarding the warehouse layout are given. Lastly, a general recommendation to Instalsolutions is provided.

6.2.1 Recommendation working structure

We recommend a working structure is made once for each sub-assembly, this should be printed and laminated. Each final product should have a box and colour next to the production area in which all production procedures are saved. In this way, it is easy to distinguish the final products and the production procedure can be easily found. The implementation of the production procedure will decrease the production time and increase the consistency of the sub-assemblies. If the welder executes the production procedure as mentioned each sub-assembly should always look the same independent of who made it. This will help to increase the production quality of Instalsolutions.

6.2.2 Recommendation production process

We recommend Instalsolutions to gather the following data to create a more specific simulation model of the production process of Instalsolutions.

- Production time of Instalsolutions for each sub-assembly specified per working station as specified in Figure 5 and Figure 6.
  - Cutting pipe
  - Thread making
  - Spot Welding
  - Actual welding
  - Pressure welding
- Welding certificate needed for each sub-assembly
- Welders working at Instalsolutions, and which certificate each welder has
- Which sub-assembly is made by which department (stainless-steel/carbon-steel)
- Time needed to assemble each sub-assembly to the container
  - Number of people that can work on this simultaneously
- Time needed to cut out holes of container (10-100, 10-300, 10-500, 10-600)
  - Number of people that can work on this simultaneously
- Time needed to assemble frames to the container (10-100, 10-300, 10-500, 10-600)
  - Number of people that can work on this simultaneously and if it will interfere with the stainless-steel or carbon-steel production line
- Time needed to insulate the container
  - Number of people that can work on this simultaneously
- Time needed to assemble the piping sub-assemblies to the container.
  - Number of people that can work on this simultaneously and if it will interfere with the stainless-steel or carbon-steel production line

Number of people qualified and available to work on the assembly of sub-assemblies, cut out holes, assemble frames, insulate and assembly piping to containers at Instalsolutions

Based on the more specific simulation model the bottleneck within the carbon-steel and stainless-steel production line can be determined. Once the bottlenecks are determined Instalsolutions can investigate ways to relieve the bottlenecks to create a better workflow.

6.2.3 Recommendation warehouse layout

We advise instalsolutions to gather the following data to determine the safety stocks and to come up with a product-specific warehouse layout and an efficient storage location for the buy-in products and sub-assemblies.

- The size of the raw materials
- The weight of the raw materials
- The frequency a product is used, will be split up into high usage, normal usage, and low usage.
- The location of rejected products
- The location of the production line at which the raw material is needed
- The safety stock needed based on:
  - Lead times buy-in products
  - Production time
  - Demand
- Measurement of the buy-in products

Once Instalsolutions gathered the points specified above the storage space needed to store all necessary products can be calculated. Based on the storage space needed the best suitable warehouse layout for Instalsolutions can be selected from the layouts provided in this research. Instalsolutions can start creating a product-specific warehouse layout which will reduce the search time for products and many more benefits, such as increasing the employee's motivation, increasing the efficiency of the employee, and increasing the production rate.

6.2.4 General recommendation

We recommend Instalsolutions finish implementing the working structure and gather the further specified data needed for the simulation. Once the information is gathered a new gradation assignment could be to create a further specified simulation model which takes the new insights into account. Furthermore, the implantation of the working structure will help Instalsolution to gather the data needed to decide how much storage space is needed. Based on this information, Instalsolutions can select one of the designed warehouse layouts and create a product-specific warehouse layout.

6.3 Discussion

In this section firstly, the assumptions that are made in this research and the impact of the assumptions are discussed. Secondly, the limitations of the research are stated.

6.3.1 Assumptions within this research:

Within the research, we assume there is enough demand to sell all products produced. This means the production process will be continuous, so there is no need to wait for the next demand. This assumption is reasonable since HoSt bioenergy systems wants to increase the production rate of Instalsolutions to 100 products or more in the upcoming years.

Within our model, we assume that customers are willing to wait as necessary to receive the products and will not go to a competitor. Once the customer enters the model it can only leave when the product is delivered. This assumption is reasonable since there are only limited suppliers of the biogas upgrading systems.

Lastly, we assume the needed raw materials are always available. We make this assumption since the expectations are that steel prices will rise because of the war between Ukraine and Russia. Because of this Instalsolutions has increased the stock levels so there is enough raw material on stock for the next year.

The carbon-steel and stainless-steel production line

The production times within the carbon-steel and stainless-steel production lines are not available, so we assumed that all production steps within the carbon-steel and stainless-steel production lines on average have the same production time. Because of this assumption, we expect WIP buffers will help to reduce the idle of the machines and help to create a fluent production line.

Instalsolutions is not yet producing according to a clear work structure. We assume this will lead to high variations within the production times of sub-assemblies.

We assume that multiple people can work on the stainless-steel and carbon-steel production line at the same time. Because of this, the sub-assemblies will always be ready before the assembly-production line needs the sub-assemblies.

The assembly production line

Steps done by external companies have unlimited capacity. Because of this steps six to step nine of the assembly production line are assumed to be fixed and do not have any capacity constraints.

We assume that no jobs can be done simultaneously, so the working hours on each step in the assembly line are the total time needed for the assembly.

There is no data available on how many employees can work at the different steps of the production line, in other words with how many people the 120 hours of Cutting frames can be finished. Because of this, we assumed only one person is working at each station within the simulation.

6.3.2 Limitations of this research

Instalsolutions is working hard on ways to optimise the production process but is still in the middle of the change process. Because of this, the software in which Instalsolutions gathers the data is not finished yet, which means a lot of data is not gathered yet. For this reason, throughout the whole research, we ran into the challenge of limited available data.

6.4 Future Research

Instalsolutions is working hard to create a structured database to get the data in order. Once Instalsolutions has the master data in order, an enterprise resource planning (ERP) system will be implemented. The ERP will support the production process of Instalsolutions and provides insights into the materials and people needed for the production process. Once the ERP system is up and running and the data mentioned in Section 6.2 is gathered there are two follow-up research projects which can be conducted.

Firstly, follow-up research regarding the production process of Instalsolutions can be carried out. In this research, the carbon-steel and stainless-steel production lines can be modelled in more detail. In this model, the production lines should identify each step into multiple production steps to investigate which steps can be executed simultaneously to increase the production rate. Furthermore, the bottlenecks within the stainless-steel and carbon-steel production lines can be identified. Furthermore, the 10-100, 10-500 and 10-600 should be modelled within the assembly production line.

Secondly, follow-up research regarding the product specified warehouse location of Instalsolutions can be conducted. Once the ERP system is up and running more insights into the necessary buy-in articles and the measurements of these buy-in articles should be provided. Furthermore, data regarding lead times can be gathered. Based on this information and the production forecast the safety stock can be calculated and a product-specific warehouse can be designed.

HoSt bioenergy systems wants to expand Instalsolutions within the upcoming 2 to 3 years to an organization of 300 employees. We think instalsolutions will benefit a lot if before any expansion happens the master data is in order, the ERP is up in running and the working structure is implemented. The working structure will help to standardize the production process and gather the necessary data as mentioned in Section 6.2. Once the data is gathered and new research should be performed to identify the bottlenecks within the stainless-steel production line and carbon-steel production line. Research can be performed on how to relieve the bottlenecks as much as possible and the most efficient workflow of Instalsolutions can be determined. Lastly, if HoSt bioenergy systems will increase the organization to 300 employees it is necessary to investigate different production plants. In this production plant there should be more space to work on more containers simultaneously and research should be performed on the necessary storage space within the warehouse.

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Appendix A: Guideline Plant simulation Instalsolutions
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