Package Concept for High Variation Products to Improve Production

Package Development and Implementation to Improve Production of Heavy and High Variation Products

Oliver Hjertstedt Otterström

Supervisor: Micael Derelöv
Examiner: Mats Björkman

Abstract

Within the Master's program in mechanical engineering at Linköping University, this thesis project unfolds in collaboration with Metso Sweden, specifically at their Sala factory. Focused on addressing challenges in packaging processes for Metso's VASA-line slurry pumps, the project endeavors to devise a concept that not only meets global shipping requirements but also enhances factory output.

The research unfolds with an exploration of the background, emphasizing the complexities of manufacturing large-scale pumps for heavy-duty industries. Operating in 45 countries with a workforce of approximately 16,000 employees, Metso's site in Sala specializes in pump production, particularly for the mining industry. The unique nature of slurry pumps, designed to handle liquid solutions containing solid particles, necessitates a tailored approach to packaging.

The identified problem lies in the high variation of pump configurations, demanding flexibility in production and packaging. Currently, custom-made packages are crafted by experienced operators, and is lacking feedback on their performance. The packaging process involves standard pallets or custom-made packages, with the latter lacking standardization and documentation, introducing uncertainties in transport.

This study aims to improve overall efficiency at Metso by addressing bottlenecks and knowledge gaps in packaging, focusing on the VASA-line slurry pumps. The goal is to present a concept that aligns with global shipping requirements and has the potential to significantly increase factory output. The findings, supported by production analysis and a detailed implementation plan, estimating a 3.38-fold increase in current production capacity.

The thesis utilizes production analysis methods in supporting product development and optimizing packaging processes. It further highlights the influence of global shipping requirements on production dynamics, necessitating additional steps in package assembly. With a focus on time rather than costs, this thesis positions itself as a practical guide for enhancing production efficiency within a constrained time frame.

In summary, this thesis unfolds as an exploration of packaging challenges, offering tangible insights for product development in a production setting and package development, especially in the context of global shipping.

Nomenclature

Phrase	Description
CT	Change over time. Time it takes for an operator to move between tasks
CTU	Cargo transport unit
EPAL-pallets	Standardized pallet used in EU, with a safe working load of 1,500 kg
ERP	Enterprise resource planning
Fixture	Part that fixates a product
GT	Group Technology, production analysis to group similar products
JiT	Just-in-Time, connecting production rate to customer demand
VSM	Value stream mapping

Nomenclature

Symbols	Description
F	Force $[N]$
g	Gravity acceleration constant $[m/s^2]$
m	Mass $[kg]$
σ_y	Yield strength, is maximum stress a material can handle before plastic deformation $[N/m^2]$
T_c	Cycle time
T_h	Time consumption for handling of product
T_o	Time consumption of main task
T_t	Time consumption for handling of tools
T_{takt}	Takt time
Q_{dd}	Daily quantity of units demanded

Contents

List of Tables

List of Figures

1 Introduction

This project is the master thesis of the Master in mechanical engineering program at Linköping University and is conducted in collaboration with Metso Sweden. It is conducted at Metso's factory in Sala where they are producing large-scale pumps for heavy duty industries.

1.1 Background

Metso is a global company operating in the mining industry, and operates in 45 countries and employs around 16,000 people. This project is conducted at their site in Sala, Sweden where they focus mainly on producing pumps and handling spare parts for pumps. The pumps are used in different industries, but primarily in mining where the pumps transports the mined materials together with ground water for further treatment. The pumps are designed to pump a liquid solution containing of solid particles, in different size and form. This mix of liquid and mined material is called slurry, and the pumps is called slurry pumps [2]. The solid particles in slurry often contains hard materials, e.g metals, creating high demand on the materials used in the pumps. Causing the pumps to be very heavy relative their size.

Figure 1: Picture of a VASA-pump.

Metso offers different series of slurry pumps, and this project focuses on their VASA-series, see figure 1. The VASA-series have two subcategories, VASA and VASA Heavy Duty (HD). Both VASA and VASA HD is a horizontal pump, indicating that the pump shaft is placed horizontally. VASA-line pumps have big size differences, where the smallest pump weighs 340 kg and the biggest weighs almost 9.5 tonnes. Figure 2 shows a sketch of a VASA HD pump and parts of interest. Both VASA and VASA HD pumps have heavy pump houses, shifting centre of gravity away from the center of the pump towards the pump house. This is an issue during transportation and handling of the pump, primarily because lifting a heavy item with eccentric centre of gravity increases risk of falling when tilted.
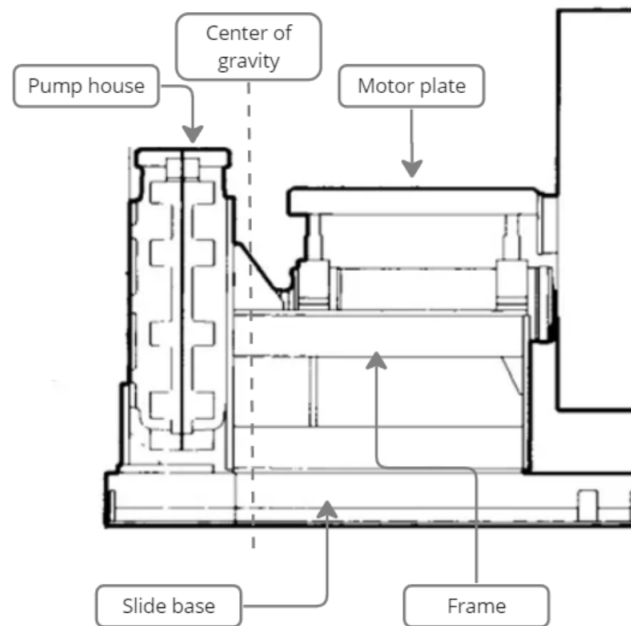
Figure 2: A sketch which shows a VASA HD pump and some of the parts are specified, as well as the center of gravity for the pump.

The product offering is modular, suiting customers individual applications. It creates high variation of the parts in the pump, affecting primarily the weight. The specified parts in figure 2 are some of the parts that are modular product offerings.

Metso is today building custom made packages for a majority of the pumps. These packages are built in the factory, at the delivery station, by experienced operators. The packages built after the pump has been delivered to the delivery station, where an operator takes measurement and start building the package.

A package is constructed by different parts; pallet, sides, top, lifting points and fixating points, see figure 3. A package's main objective is to move a product from one place to another without damaging the goods or environment.

Figure 3: A package (left) and a side (right) which is used by Metso when this project is conducted. Sides and pallet are clearly shown in the figure. The top is mounted on the sides, and lifting points are between the beams of the pallet.

This thesis project focuses on creating a solution which increases efficiency in packing of a variety of products in a safe and secure manner. It should be a safe delivery and handling both for the pump and people around it. The packaging process is also susceptible for increased risk if employees work in a stressful environment.

1.2 Problem Formulation

As mentioned, Metso is producing a high variation of pumps, and pump configurations. It requires flexibility in production to work efficiently as every order is different. Furthermore, packing of the high variation pumps requires a flexible packaging station or solution. Flexibility is currently gained by having operators build custom made packages for each pump. The operators design the package from experience, but lack information flowing backwards, not getting any feedback of how the packages performs during use.

Packaging of the products is split into two categories: use of standard pallets or custom made packages. When using standard pallets, the most common one is the EPAL1-pallet which is the most common pallet used in the European Union today [1]. The EPAL1-pallet have a safe working load of 1,500 kg when evenly distributed, which holds some of the pumps but a majority of the pumps requires custom made pallets. The custom made packages, as they are built from experience, are not standardized, verified or documented. This creates an uncertainty during transport if the package fulfills the different requirements a package needs to have. It is also problematic if problems occur, as there are no traceability and thus possibility to identify issues in the package or process building the package.

There are limited data gathering from the packaging process, with no data existing about time consumption regarding packaging. Planning of the delivery station is done by an estimation from the operators and people in the planning organization. This creates an uncertainty regarding resource utilization, identify issues and lead times for the pumps.

When the pump arrives at the packing station the process of building the custom made package starts. In rare instances, where an order arrives of multiple of the same type of pumps, the package is prepared in some way, such as building sides before the pump arrives. However, working this way makes the packing station susceptible for variation in demand. If there is a sudden increase in demand which under normal circumstances would be acceptable, it can lead to bottlenecks at the packaging station.

The custom made packages and pallets are built in wood, ISPM-15 certified [3], and are stored in a room next to the packing station. There needs to be a lot of different wooden planks in that room to fulfill the demands of the different packages built. As there are no knowledge about how the packages are designed, no one know for sure the amount of wood needed. This leads to increased risk of either purchasing too much or too little wood.

1.3 Purpose

The purpose is to improve overall efficiency of production at Metso, by focusing on packaging of pumps. Solving challenges like bottlenecks and lacking knowledge about time consumption connected to packing. Furthermore, the result aims to free resources and increased potential output of pumps from the factory. The overall improvements will also improve well being of operators, reducing stress and risk factors in production.

1.4 Goal

The projects goal is to present a concept which will improve packaging and handling of Metso's VASA-line slurry pumps. While fulfilling the requirements of a package operating in global shipping, the concept has potential for increased output of pumps from the factory. The result is to be substantiated with information from production analysis and product development methodology. This is presented with a production analysis and implementation plan showing in which way, and how much the production can improve based on estimations.

1.5 Research Questions

This section presents the research questions for the project which is studied during the development to reach the goal.

- **RQ1:** What information is needed to develop a target specification for a product intended to be used for global shipping?

- **RQ2:** How is the requirements for global shipping affecting the product's ability in a production setting?

- **RQ3:** How can production analysis methods support product development for a product intended to be used in and improve production?

1.6 Limitations

A few limitations are noted for the project:

- The solution should be suitable to the time available, which is 20 weeks.

- Limited data gathering currently at Metso.

- Not all VASA-pumps have drawings in their internal databases.

1.7 Delimitations

Limiting the scope of the project will ensure that the goal is met during set time period. Decision has been made to limit the project to pumps which are exclusive to their site in Sala, which is the VASA-line of slurry pumps. Metso have a few products which are sold in low volume and are customer specific orders which leads to no demand of standardized package, making it outside the scope of this project. The project is focusing on the packaging station at the factory in Sala, and analyzing only this station.

Deciding whether the solution will be profitable needs economical analysis and this will be delimited to include:

- Cost of personnel

- Material cost

Specific data will not be gathered nor possible to share, which makes the work to not focus on costs in production but rather on time. Analyzing ways to reduce time consumption building and handling the package.

2 Theoretical Areas of Focus

This chapter covers the different areas of focus of the project.

2.1 Product Development

Product development covers the development of a solution towards the goals of the project. Existing product development methods are analyzed to suit the challenges the project have. Analyzing the different methods and the effect it have on the project is important when starting to develop a solution. The methods of choice is presented in the chapter 3,(Theory), before possible modifications are presented in chapter 4, (Method). As the challenge is to develop a solution to implement in an existing production the product development can be assisted by production analysis methods.

2.2 Production Analysis

Developing a product for use in production, or having a product linked with production can preferably be supported by production analysis. It is comparable to doing market research, where the industry or environment the product should be applied in are analyzed. It exists many different production analysis methods which needs specific data or information available. Consequently, it is important to gather information and analyze what production analysis methods are suitable for the specific case. The method of choice gives enough of information to support implementation, and development of the production. Production analysis methods are explained in chapter 3, (Theory), and how it is implemented presented in chapter 4, (Method).

2.3 Packages in Global Shipping

How to use packages in global shipping and the demands on packages due to standards, legislation, regulation and guidelines is studied. Gaining knowledge about the area of global shipping is important developing a product implemented in that area. Study different areas in shipping and how they can affect a solution is important if the solution should be able to be implemented. Furthermore, it is important gain insight about the industry of shipping, thus studying guidelines, standards, legislation and regulations is important.

3 Theory

This chapter presents the theory which is used to develop a solution, giving more information and context about the different areas of focus.

3.1 Packaging in Industry

Packaging is defined by the European Union in the European Parliament and Council Directive 94/62/EC of 20 December 1994 as:

> 'packaging' shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. 'Non-returnable' items used for the same purposes shall also be considered to constitute packaging. [4]

This directive focus is on the package and material used for this, with a goal to reduce waste from packaging and packages [4]. Another used definition is Paine's which states that packaging is a system which prepares products to be shipped and stored, but also for retail and end-use [5]. It is also stated that packaging is, to a optimized cost deliver the product safe to the customer, which is stated as a techo-economic function to increase sales. Paine's focus is more on the packing operation, compared to the EC directive.
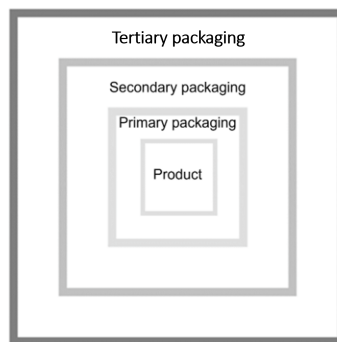
Figure 4: Description of the three different levels of packaging.

Packaging is split into three different systems as seen in figure 4, *primary packaging*, *secondary packaging* and *tertiary packaging* [6]. The different systems work related to each other and are defined by their proximity to the product. Primary packaging are closest to the product, secondary contains one or more primary packages and tertiary includes secondary and primary package. To be successful there are six functions that a packaging system should fulfill [6].

- Protection: Protect content from the environment.

- Containment: Contain the content from the environment.

- Apportionment: Scale big-sized and massproduction to manageable levels.

- Unitization: By modularization optimize the packages into one another.

- Communication: Clear information about necessary information of the packages and contents.

- Convenience: Simplification of packaging and handling.

The different functions work to improve the handling, space utilization and safety of the package [6]. It is not only important to protect the content from the environment, protecting the environment from the content could be important.

According to Griffin (1985), to be successful when packaging products, there is a need to understand its purpose, supporting marketing and distribution [7]. Packages supports marketing by using a special made package for the product, and to deliver products without defects. Furthermore, it supports distribution to enable the shipping of the products via the available routes to reach each customer. However, it is expensive to increase effectiveness of packaging, as it often creates the need of special machinery for each organization's product and package. Which reduces the incentives for companies to develop machinery for these operations.

3.1.1 Packaging Guidelines

To reach an efficient method of packing and use of packages globally there is a need to standardize packages, and how they are used [8]. Holzpackmittel Paletten Exportverpacking (HPE) has done this in their packaging guideline, where they compile standards and legislation for different areas of packing. They present different standards to follow, and different aspects which needs to be considered during shipping. A package's main objective is to take a product from the seller to a buyer, but this includes a lot of different steps and challenges. The product that is being shipped also has a big impact on how a package should be designed. Is the product heavy, fragile or consists of dangerous substances? It all creates different demands on the package and how to transport the product between the seller and customer.

3.2 Package for Global Shipping

Packages and their content needs to be prepared for shipping to a range of different countries, and their respective regulations. When shipping globally there is a need to know international standards and regulations, but also what and if specific regulations exist in the countries the package is moving through. Australia is one of the toughest countries regarding choice of package, and will stop a package from entering the country if it does not fulfill their standards [9]. If the package does not fulfill their rules, it will either be sent back or repacked off-shore, with a hefty fee included. However, they provide the steps that need to be fulfilled to comply with their standards and facilitate import. This is one example, but to have all the information before shipping to a specific country will significantly reduce the risk of time- and economic loss due to faulty packaging.

3.3 Containers

A lot of different containers are used to suit different types of cargo. Table 1 specifies the different types of containers, and their minimum internal dimensions. These are the most common containers and are following ISO 668:2020 [10]. This standard specifies external dimensions, minimum internal dimensions and maximum gross mass [10]. The measurements are taken according to figure 5, but on the inside.
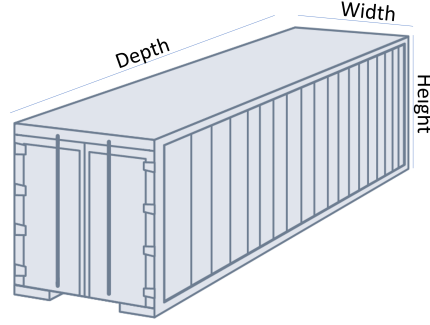
Figure 5: How the dimensions are taken on the container. These dimensions are used, but on the inside of the container. Picture is taken from [11].

Table 1: Container types and minimal internal dimensions [10]. HC means High Cube.

	Container	Height [mm]	Width [mm]	Depth [mm]
	Dry	2,250	2,280	5,890
20"	Open Top	2,280	2,280	5,890
	Flat Rack	2,250	2,400	5,600
	Dry	2,280	2,280	12,000
	Dry HC	2,570	2,300	12,000
40"	Open Top	2,280	2,280	12,000
	Open Top HC	2,650	2,280	12,000
	Flat Rack	1,950	2,400	11,600
	Flat Rack HC	2,250	2400	11,600

Side walls are capable of withstanding 60 percent of permitted payload, and front wall and door capable of 40 percent of permitted payload [12]. To secure the cargo and make the environment safe during transport there is a need to fixate the cargo within containers [8]. There are different ways to secure a package within a container, but the most common is by straps, nylon or metal, which are connected to the package.

3.3.1 Weight Distribution

Weight distribution of the package is important when loading into a container [12]. This is due the durability demands that a container has, which is calculated with a homogeneous load [10]. If a container needs to be evenly loaded, it means that the packages should strive for a homogeneous weight distribution as well [12]. If the packages' weight is not evenly distributed it could lead to increased handling times and increase cost for shipping.

3.4 Load and Stresses on Packages during Shipping

During shipping there are different strains on a package. From the product, if it is heavy the package needs to be strong, securing the product in order not to harm anyone, anything or itself. From the transportation, loads during transportation such as acceleration forces due to braking, bumps or waves. A product is packed in packages designed to suit different loads, therefore weights of a product [8]. These standardized packaging solutions work for some products, while other need a custom made solution.

During shipping different factors affects the package, such as mode of transportation. Transportation by sea have the highest strain on a package and the product, causing tough demands on packages used on ships [8]. To determine stress and load levels it must be known if the packages are stacked. If packages are being stacked, which is an efficient use of space, it will cause higher stress levels on the packages close to the bottom [13]. However, the mode of transportation can cause unpredictable loading directions and strains, especially when using transportation by sea. Train, air and road transportation have more predictable loading directions [8]. Table 2-4 shows the different acceleration loads on a package using different transport modes [12]. In these tables the forces applied is specified as longitudinal, transversely and minimum vertical down [12]. These forces are relative to a Cargo Transport Units (CTU) orientation, see figure 6. Minimum vertical down can be described as a lift force, and acts in a vertical direction relative to the ground. Longitudinal acceleration force is split into forward and backward direction, applies during acceleration. Transversely is sideways compared to the loading and motion direction.

Figure 6: Visualization of the orientation of acceleration forces on a ship, but applicable on other CTU's as well.

Table 2: Describes different acceleration coefficients when in road transport, multiplied by the gravity acceleration, $g = 9,81 m/s^2$ [12]. The forces described are relative to the trucks orientation.

Road transport				
Securing in	Acceleration coefficients			
	Longitudinal (c_x)		Transversely (c_y)	Minimum vertically down c_z
	Forward	Backward		
Longitudinal	0.8	0.5	-	1.0
Transversely	-	-	0.5	1.0

Table 3: Describes different acceleration coefficients when in train transport, multiplied by the gravity acceleration, $g = 9,81m/s^2$ **[12]**. The forces described are relative to the trains orientation.

Train transport				
Securing in	Acceleration coefficients			
	Longitudinal (c_x)		Transversely (c_y)	Minimum vertically down(c_z)
	Forward	Backward		
Longitudinal	0.5 (1.0)	0.5 (1.0)	-	1.0 (0.7)
Transversely	-	-	0.5	1.0 (0.7)
Values in parenthesis are shock loads and used for calculations and only during 150 ms [12].				

Table 4: Describes different acceleration coefficients when in sea transport, multiplied by the gravity acceleration, $g = 9,81m/s^2$ **[12]**. The forces described are relative to the ships orientation.

Sea transport				
Wave height	**Securing in**	Acceleration coefficients		
		Longitudinal c_x	Transversely (c_y)	Minimum vertically down (c_z)
A: $H_s \leq 8m$	Longitudinal	0.3	-	0.5
	Transverse	-	0.5	1.0
B: $8m < H_s \leq 12m$	Longitudinal	0.3	-	0.3
	Transverse	-	0.7	1.0
C: $H_s \geq 12m$	Longitudinal	0.4	-	0.2
	Transverse	-	0.8	1.0

Vibrations is another aspect which must be considered due to the risk of fatigue failure or screws unscrewing [13]. There are two general types of vibrations, irregular and regular, where regular vibration stress may be caused by power units of the vehicle [13]. Regular vibrations can cause chafing and shaking. Irregular vibrations are usually caused by the road or route the vehicle is moving on, and can cause harm to the product which is being transported if it has delicate or fragile components [13].

3.5 Pallets

Pallet acts as load carriers and are widely used in shipping, storing and material handling. Pallets have an international standard from International Organization for Standardization (ISO), but there are six different sizes used in different continents, shown in table 5 [14]. The pallets are used for designing transport and optimizing space in transport, and the use of standard pallets are needed to facilitate space optimization. There are however companies and organizations that uses their own packages, such as Volvo [15].

Table 5: ISO-standard pallets used in different regions globally

Used in:	Dimension (WxL) [mm]	Maximum weight [kg]
North America	1,016 x 1,219	2,087
Europe, Asia	1,200 x 800	1,500
Australia	1,165 x 1,165	2,000
Asia	1,100 x 1,100	1,750
North America, Asia, Europe	1,067 x 1,067	1,678

3.5.1 EPAL

EPAL-pallets is standardized pallets accepted by a wide range of countries and the biggest open pallet exchange pool [1]. EPAL has different standards and do not produce any pallets themselves, but takes a licensing fee for the inspection of production and repair of EPAL pallets [16]. EPAL pallets has a few requirements that needs to be fulfilled to receive EPAL's classifications [1], see chapter 3.5.2 and chapter 3.5.3.

3.5.2 EPAL Pallets

EPAL has a range of pallets to suit different needs [1]. The most used is the EPAL1-pallet, or Euro pallet, which specifications is listed below, in table 6. The EPAL1-

Table 6: Specifications of EPAL Euro pallet [1].

Boards	11
Nails	78
Blocks	9
Length	800 mm
Width	1200 mm
Height	144 mm
Weight	ca 25 kg
Safe working load	1500 kg

pallet is combined with the EPAL3-pallet which handles highest safe working load of 1,500 kg, if the weight is evenly distributed [1].

3.5.3 ISPM-15

ISPM-15 stands for International Standards for Phytosanitary Measures number 15, and is a guideline for regulation wood packaging material globally [3]. ISPM-15 is the 15th volume of these measures and is applied globally to packaging materials, and this is to minimize the risk of spreading or introducing quarantine pests associated with wood. ISPM-15 is regulating what materials that are authorized to use, and what treatment that material has to undergo to be approved. It specifies different treatment methods to certain wood types and how to label wood that has been treated in the correct way according to the standards, see figure 7. If this standard

is not fulfilled, or not marked on the wood used on the package, there is a big risk of the package being returned or treated at port costing a lot of money and time.
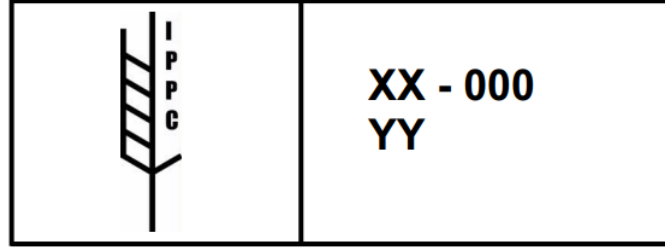
Figure 7: ISPM-15 marking for approved measures. It includes the symbol, an ISO-two letter country code, (XX), the specific producer code (000) and a code to what treatment the wood has undergone according to the ISPM-15 standard [3].

3.5.4 Construction Standards for Packages

The weight of the products has a big impact on how the package is constructed [8]. However, it is not only the geometrical design that is affected, choice of material is also an important aspect to consider. Current standard is to use wood for most applications in packaging, but it has a big difference in strength depending on loading direction [17]. However, what material used is not determined by standards but rather on suitability in different applications. Packages has demands to be possible to fasten in the container, in order to keep it in place during transportation, removing risk of damaging goods, environment or humans [8].

3.5.5 Durability Calculations

Durability calculations are done to ensure that the applied forces do not break the part exposed [18]. Calculating maximum stress gives an indication about the strength needed in the part. Maximum stress can be compared to yield strength of materials, knowing if the part will elastically deform during the applied force. This equations is built on the assumptions that cross sections of the beam does not deform significantly when transverse or axial loads is applied, and is assumed rigid.

$$\sigma_{y,max} = \frac{FL}{CZ} \tag{1}$$

Where C is dependent on how the beam is fastened to the environment, and Z depends on geometrical properties of the part. Leading to possible comparison between yield strength of the material and the maximum stress applied on the part.

$$\sigma_{y,max} \geq \sigma_{max} \tag{2}$$

3.6 Ulrich and Eppinger's Product Development Method

Ulrich and Eppinger's product development method is a method which focuses on how to develop and analyze concepts. It creates a framework of where and how a project should use their resources in a efficient manner. Ulrich and Eppinger's method can be described in the following steps [19]:

1. Identify customer needs

2. Establish target specification

3. Generate product concepts

4. Select product concepts

5. Test product concepts

6. Set final specifications

7. Plan downstream development

The different steps are covered in following sections.

3.6.1 Identify Customer Needs

Customer needs are identified from a range of different sources and stakeholders [19]. The stakeholders are split into two categories, internal and external stakeholders. External stakeholders often include users of the product (customers), legislation organs and authorities, suppliers, resellers, and service persons. Internal stakeholders often include manufacturing operators, engineering disciplines, routines, managers and marketing. These sources combined gives an understanding and a broad perspective of what the product needs to fulfill to be successful.

However, it is important to understand the limitations when asking people closely involved with a product [19]. People tend to have harder to see bigger changes that may improve performance of an existing product, which needs consideration when gathering data talking to people. Trying to identify the hidden needs is solution to that challenge, which is a way to find where the possibilities or must-be attributes are. Hidden needs are interpreted from statements and conversations around the subject, and not necessarily about the obvious problem. The specified customer needs are interpreted to suit product development and then translated into a target specification.

3.6.2 Target Specification

Target specification is developed after the customer needs have been specified and interpreted [19]. Target specifications are based on the customer needs and competitive benchmark information. The targets are specified by metrics, which should explain what the solution needs to fulfill and it should be possible to measure these metrics. The design should influence the metrics, making the metrics dependent on the solution, and thus making it possible to measure the solutions performance

relative to the metrics. However, some metrics are not possible to quantify in a way that makes it possible to measure, thus needing subjective metrics.

The target specification shows desired range of the metrics, but also the critical value it must exceed to be classified as a potential solution [19]. These values are drawn from calculations, but also comparison to the current market. The target specifications are ideal values and what to strive for, but as they are developed before a solution is known it is common to not meet all but exceed others and these specifications should because of this be updated during the project.

3.7 Liedholm's Systematic Concept Development

Liedholm [20] splits concept development into three different phases. Where the *first phase* is to analyze the problem from a critical view and analyze feasibility and competition before creating a design criteria list, listing the requirements [20]. *Second phase* is a function analysis, where first a black-box model should be established to analyze what the main goals are. The black box consists of three different areas: input, output and main function. This is done to ensure that the technical principles established in the next step fulfills the main goal of the project. A transformation system specifies and breaks down the technical principles established. Furthermore a mapping of the functions is done, preferably in a tree-structure, showing problem and different solutions to this problem.

Third phase and the final phase is development and implementation of the concept [20]. Concepts are developed to suit the previous phase's specified functions and challenges. After the creation of the concepts, they should be analyzed and improved, before a correction to the design criteria list is done. Final step is to plan future work for the concept.

3.7.1 Design Criteria List

Design criteria list is a specification of what abilities a product or process needs to have in order to fulfill the goals [20]. The list is developed with help of a checklist specified by Liedholm, to not miss any important information. However, this list is updated during the project to suit the development. Which, when more knowledge is gathered about the product and area, can be more specific.

This list is completely unbiased towards any solution and focused on the requirements for that specific solution [20]. After completion of the the design criteria list, a main function is determined. This function is completely free from solution bias. Liedholm presents the checklist with six different areas to have in mind:

1. **Comparable:** If an ability is able to be ranked regarding the design alternatives it is deemed to be comparable.

2. **Requirements or Preference:** An ability of the product should be clearly defined to be either a requirement or a preference.

3. **Standard:** Following current standards, regulations and guidelines in the area the product implemented in.

4. **Free from solutions:** An ability should be free from possible solutions that can introduce bias or decrease innovation in a design process.

5. **Able to measure:** It should be able to measure the ability, to know if it is fulfilled or not.

6. **Non-redundant:** An ability should not be covered by multiple statements as it can introduce uncertainty in the decision process.

3.7.2 Black Box

Black box is mentioned in different methods, both Liedholm [20] and Ulrich and Eppinger [19] are using it. They are doing it a bit different, as Ulrich and Eppinger are specifying which actions are being done while Liedholm is not. Liedholm's [20] black box consist of three areas, input, actions, and output, see figure 8. However, before the development of the black boxes an *operand* should be determined, which is the item that should be transformed into something different. It is possible to have multiple black boxes to fully explain the operations, as well as determining operands to the white boxes [20].
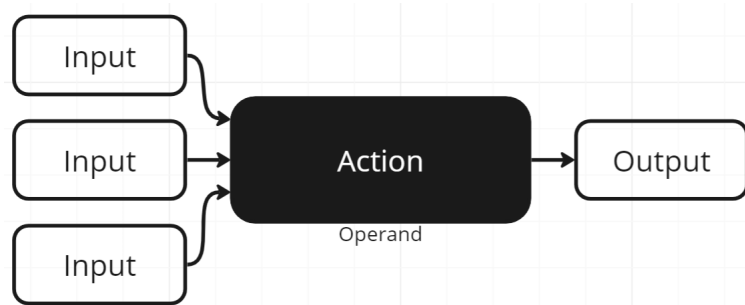
Figure 8: Definition of a black box.[20].

The middle box of the black box explains the main functions of the products purpose [20]. The input is explaining what products or energy is needed to fulfill the output. The output is the final stage and fulfillment of the goal. The actions are what is needed to be done to the proposed solution to reach the output. This is often referred to as decomposing a problem functionally [19].

3.7.3 Technical Principles

The technical principles make use of the gathered information, and is specifying different ways to solve the problem. This is done by analysing competitors, what the market is using, but also brainstorming activities [20]. The principles includes different possible solutions to the same problem. When analyzing and choosing between the different principles, only the principles which are obviously bad should be removed. If trying to pick what seems the best alternative at this point, there is a risk of missing better alternatives. Liedholm presents three focus points regarding the technical principles:

- Obvious pros and cons

- Is the project technological feasible if this principle is chosen?

- Is the project economically feasible if this principle is chosen?

3.7.4 Transformation System

A transformation system is a schematic visualization of the technical principles [20]. The transformation system is split into two different areas, establishing technical process for each operand and who or what that will conclude the transformation.

Establish the technical process for each operand's transformation, where a transformation can be a change in inner or outer structure, position or time [20]. After the transformation's technical processes have been developed their relevance, if it is reasonable and the order of the processes is evaluated. A general transformation system without specified technical processes is shown in figure 9.
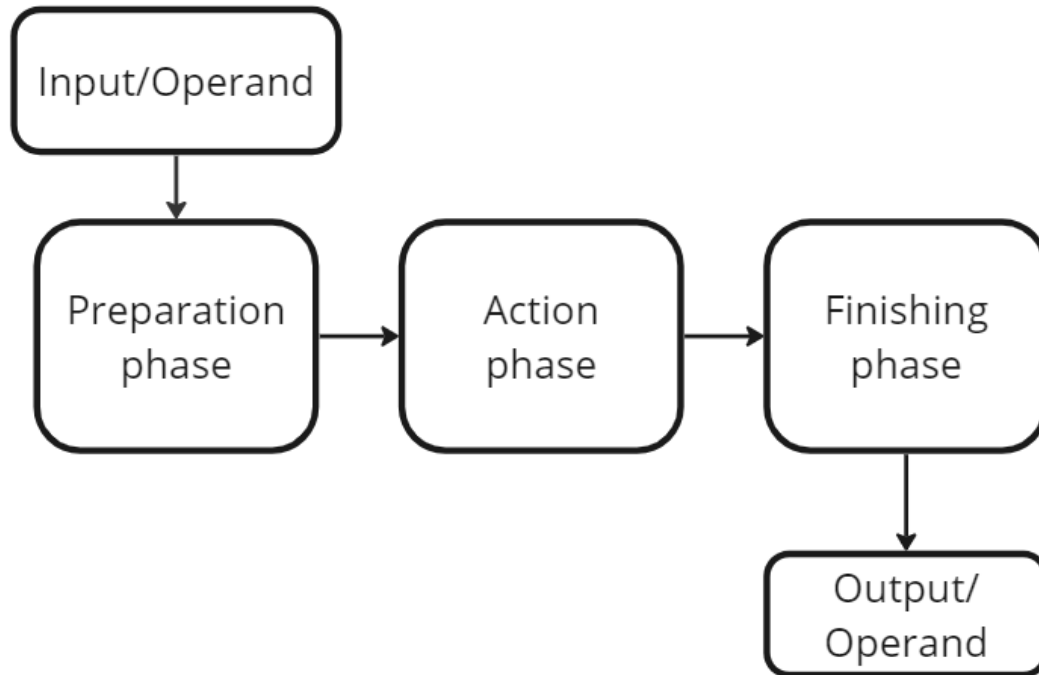
Figure 9: A general schematic view of a transformation system.

3.8 Ullman's Design Process and Product Discovery

Ullman advocates for continuously approving steps that have been developed to ensure stakeholders are informed but also has the possibility to come with feedback of the progress [21]. The evaluation of each progressed step is an important part of a project, leading to reflection and possible improvements of the process. Ullman's method includes more steps, but are not relevant for this project due to how it is implemented.

3.9 Production

This section covers different theories and methods regarding production and production analysis.

3.10 Production Systems

Bellgran and Säfsten [22] define a production system as

> The process of creating goods and/or services through a combination of material, work, and capital is called production. Production can be anything from production of consumer goods, service production in a consultancy company, music or energy production. [22].

A production system consists of different entities and structures but have a few similar groups [23]. This system can be viewed as a hierarchical system where the production system is split into two categories, *facilities* and *manufacturing support system*. Which in turn consists of different subcategories, see figure 10.
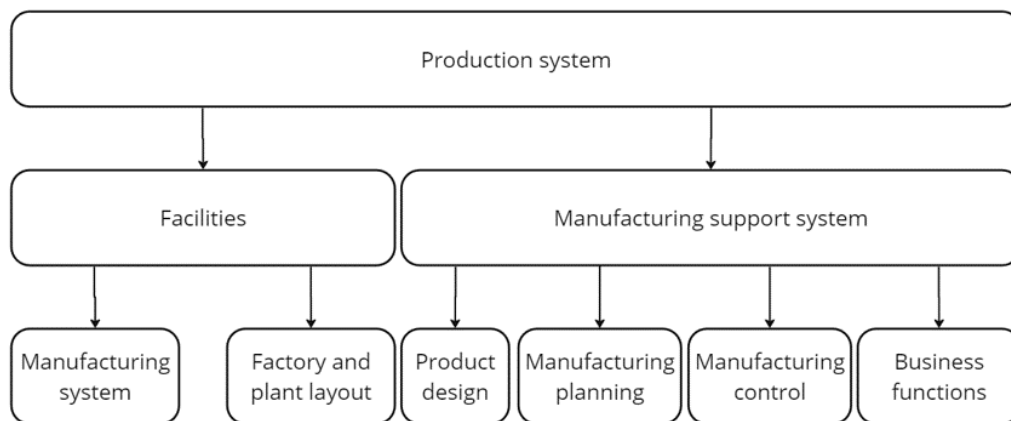
Figure 10: A general production system and its different categories [23].

The subcategories can be more or less autonomous with help of automation or computerization [22]. Two types of computerized systems that can be used are enterprise resource planning (ERP) and manufacturing execution systems (MES). ERP is a system which supports the daily planning of business activities in different parts of an organization, such as project management, HR, accounting, risk management and supply chain operations for example [23]. It is a broad system which aims for an integration of all data required to perform business functions in the organization.

MES is a system which focuses more on manufacturing and activities performed on the line [23]. It gives further insight about key performance indicators (KPI) and gives a structure to the data gathering, thus making it easier to draw conclusions from the data. A MES often includes functions to control in real time, inventory levels, machine utilization and labour tracking.

3.11 Information and Material Flow

Information and material flows has been identified but there are different ways that this can flow through the factory. Following sections covers different ways to handle material and information flow in different circumstances.

3.11.1 Product Variety

Product variation impacts the planning of the production and all operations must be planned to suit the products produced [23]. If variation of products exists, there is a need to handle the variations in an efficient way. There are three major areas covering product variety, and how to handle that, hard variety, soft variety and no variety. Hard variety is defined as big differences between products, the differences that exist are substantial and have major effect on the production planning. Soft variety is defined as minor differences between products, which could be different models of one product. No variety is when there is one type of product, without differences. See chapter 3.12 for how the different variations are handled in the production.

3.11.2 Internal Logistics

In this context internal logistics is considered to be flow of products or parts within the company, and primarily within one site [23]. Internal logistics is how parts are being moved through the factory. A product consists of multiple different parts which all needs to be assembled into the final product. How the assembly is done depends on the products design, and the order of its assembly operations. And when should parts be delivered to certain stations, and is there any structured sequence that the products follows when delivered to assembly stations?

If looking on how one product is moved to a specific station there are multiple ways of doing this.

- **Refilling:** Linear flow through the factory and to its final destination. Using a push system.

- **Refilling and return:** Similar to refilling but parts that are not used are reverted back to their storage space, either at the buffer area at the station, or in some other storage.

- **Kitting:** Preparing the exact amount of parts needed for performing an operation at that station.

- **Sequencing:** Sequence the linear flow of products to match in what order they are needed to perform an operation.

- **Batch supply:** Handle same type of products in batches.

Each of the different ways to handle the flow of parts has advantages and disadvantages, and should be suited to the specific situation in different factories.

Refilling is an easy way to handle the parts as they do not need any excessive

handling when they arrive to the factory [23]. However, it will need a buffer area at the assembly station as it is not certain that the delivered part at the assembly station will be the one that is needed. It will create a problem when there are many different parts that are needed, demanding a lot of inventory at each assembly station.

Refilling and return frees up space compared to only refilling, as it is returning the parts that are not used [23]. The parts delivered to the station are used in assembly of specific parts, but when the station is done assembling the products the parts are being transported to another storage, and not stored at the workstation.

Kitting is to prepare the exact amount of parts that needs to be assembled into kits [23]. The kits are delivered to a workstation where an operation is performed, often assembly. During this operation the operator has the exact number of parts for one specific product, before moving to the next product or kit.

Sequencing is when the parts arrived to the workstation in the sequence it should be handled during an operation [23]. If a product should be assembled, and the parts (A,B,C) should be assembled in that order. They arrive to the workstation in the order they should be assembled.

Batch supply is when the delivery comes in batches [23]. Which means that one type of product is assembled, and all the parts for the amount of products that should be assembled are delivered to the workstation. When all the products in that batch are assembled, the operator move on to the next batch of products, which has different parts.

3.12 Product and Part Flow

Each product variety, see chapter 3.11.1, has a recommended line type it should follow for optimized efficiency [23]. Hard product variety should follow a batch-model line, soft product variety should follow a mixed model line and no variety should follow single-model line. These different lines are different ways to flow the products through the factory. Single-model line is one product, no variety, that move through the factory and are often in large quantities. Mixed-model and batch-model lines are producing two or more type of products. The difference is that batch-model line is producing the types of products in groups, where the mixed model line is producing the different types right after each other. In batch-model production the stations are configured to handle one type of product before reconfigured to suit the next type of product. In mixed-model lines the stations are equipped to handle multiple types of products without the need of reconfiguring the station.

Usually specified during assembly or manufacturing operations where the materials or parts are moving in different ways to reach the positions of where the operations should take place [23]. This is defined by different orders, inventories or rates. There are different ways to pace a line in production and there are three ways that are used, *continuous transport, synchronous transport* and *asynchronous transport*. All presented in the following chapters.

3.12.1 Continuous Transport

This transportation method is moving a workpiece at a constant velocity through the factory and actions are performed during movement of the workpiece [23]. This transportation mode is often used in manual assembly lines and can be implemented in two ways. The product is either fixed or removable from the transportation module. The transportation module is often a conveyor moving the product through the factory.

This method of pacing the line has advantages such as predicting lead time and constant flow of products, but the issue arise when there is a problem on the line [23]. If a problem occurs, either with one of the products or the transportation system, the line stops and no products comes out of the factory. It is also a problem with changeover time, where the line needs to be stopped if one station needs to change tools, making it inflexible.

3.12.2 Synchronous Transport

Synchronous transport is moving the workpieces at a constant velocity between the stations, but when at the station they are paused to perform an operation [23]. When a workpiece arrives at a station, there is a time limit for performing the operation, making it unsuitable to manual assembly lines. This is because the risk of introducing stress to the operators performing the operation. However, it has advantages when operating in an automated line where the cycle time for the operations are clear, leading to predictable output from the production.

3.12.3 Asynchronous Transport

Compared to the other described transport pacing methods, this has a focus on the time it takes to perform an operation rather than the transportation between stations [23]. Asynchronous transportation moves the workpiece to next station when the operation is performed, and the transportation between stations is often relatively fast. Creating need of storage areas at the stations for products which has not yet been finalized at the station. This transportation method introduces uncertainty of time consumption as it can fluctuate, but gives the freedom to take a bit more time on some products if needed. Asynchronous transport is preferable in complex and low volume assembly.

3.13 Lean Principles

Lean is a philosophy that is widely established in multiple industries, but its origin is from the manufacturing industry [23]. Lean philosophy is doing more with less resources, and this is achieved by following a few principles and terms that need explanation [24].

- **Value:** Value is defined by the customer, and only what the customer is willing to pay for.

- **Value stream:** Map and visualization of the value adding activities.

- **Pull:** Information flow, which is driven by demand. Hence, you gather, *pull*, information from the areas knowing the demand and adjusting production to suit it. The information flows up within an organization.

- **Push:** Information flow which is driven by information flowing down in an organization. The stations does not have information about demand beforehand and needs to react to challenges. The information is pushed down through the organization to specific areas.

- **Perfection:** To always strive for perfect outcome, but never be complacent and always improve.

- **Value adding:** Activities that add value to the product, such as processing.

- **Waste:** Activities that does not add value to the product.

- **Auxiliary work:** Activities that support the value adding activities, such as tool changing.

- **Built-in-quality:** Refers to the quality of products in its initial build and the ability to build quality without needing rework.

- **Standardization:** Use standard ways of working and make use of expert knowledge from the operators working with and in the processes daily.

These principles are the foundation of analysis and implementation of lean in a production setting [23].

3.14   Value Stream Mapping

Value stream is all operations and actions needed to deliver the product or service to customer [25]. This is a lean principle which aims to identify where the value is, and where waste is. Value stream mapping (VSM) is where the actions are mapped and documented, and later categorized. The categorization is done by a lean view of value and waste, ($Cat.1$) actions that add value, ($Cat.2$) those that do not add value but are necessary and ($Cat.3$) those which do not add value and can be eliminated. VSM includes different information, and usually these are also divided into material flow, information flow and time line [26]. Material flow is how and where the materials or products is moving through the production [26]. Information flow is how information and communication flows through the organization and if it is a pull- or push system [26][23]. To conclude, VSM is done to understand current state and how to improve [23].

However, there is a need for an understanding of the processes and an in-depth understanding of basic concepts to link processes [27]. There is a risk of using VSM as a tool to feel like applying lean principles, but it may be deceiving if not the knowledge needed exists. There are eleven categories, which may cause problems using VSM [27]. Applying these to this project, the most relevant are *"P1: Low/Lack of integration between processes", "P5: Low/Lack of standardization and process stability, "P6: Problems/difficulties in measuring data in process* and *P8: Small batches with highly mixed production* [27].

3.15 Group Technology

Group technology is a manufacturing philosophy that makes use of categorizing products into different part families by similarities [23]. Group technology defines part families, where all parts in a part family has a set of similarities. This is mainly used in batch production, where multiple part families is used to facilitate machining cells which work parallel improving work flow, also called cellular manufacturing. Group technology is categorizing the products by a code which will indicate certain abilities, characteristics and tasks, each with the potential to improve productivity in different areas of an organization [28]. Group technology is trying to use the similarities to perform similar activities together, standardizing closely related activities and data gathering of recurring problems. However, to consider Group technology it needs to be similarities to either the part design or the part processes [23]. Determination of the groups can be done by different criteria, visual inspection, parts classification and coding, and production flow analysis. Visual inspection is most common as it uses the judgment of people to group parts into families. Part classification and coding make use of a coding scheme to identify the similarities. Production flow analysis uses the routes a part moves through production to determine part families [28]. Group technology is used to improve organization of the production facilities to match the specialities with the different part families [23].

3.16 Cycle Time

Cycle time is the time it takes to perform an operation [23]. Cycle time is determined by a stopwatch time study. This is helpful when knowing the capacity and how resources are being used. Cycle time is often split into time consumption of different tasks included in an operation. As shown in equation 3 the total cycle time (T_c) of an operation consists of different parts. T_o which is time consumption of the main tasks, assembly or processing operation, T_h is time consumption for handling the product and T_t is time consumption for handling of the tools, such as tool changes [23].

$$T_c = T_o + T_h + T_t \tag{3}$$

3.17 Lead Time

Lead time is not considering the demand of a product. It simply measures the amount of time passed from the initiation of production to delivery [23]. Lead time is used in a wide variety of industries and applied differently, but the purpose of knowing lead time is to have knowledge about how long it takes from the beginning to end of a process. In this report, lead time refers to manufacturing lead time, which is total time of a product or part through the entire of the factory [23]. It is calculated by equation 4.

$$MLT_j = \sum_{j=1}^{n}(T_s + Q_j T_{cj} + T_d) \tag{4}$$

Manufacturing lead time (MLT_j) is the summation of a batch of parts or products j, where T_s is the setup time, such as tool changes or reprogramming [23]. Q_j is amount of products or parts being processed, while T_{cj} is the cycle time for

that specific operation. Last parameter is the downtime (T_d), which explains time passed without any progress to the operation. n represents the amount of operation sequence, $j = 1, 2, ..., n$. However, lead time can be calculated in different ways, Kenton [29] suggests another equation, see equation 5. Where LT is lead time, T_{pre} is pre-processing time, T_p is processing time and T_{post} is post-processing time [29]. Pre-processing time is defined as procurement stage, and post-processing time is defined as delivery to end-customer [29].

$$LT = T_{pre} + T_p + T_{post} \qquad (5)$$

Lead times has an effect on customer satisfaction, as the customer will receive the product faster and it is a competitive advantage to be able to deliver quicker than other actors [29].

3.18   Parameters to Determine Profitability

In different sectors there are different parameters to determine how profitable a solution is, even though at the last line it is the money that counts. But how a solution for packaging is profitable differ between a production process and a shipping method. This section will present parameters in both that are important when analyzing and developing a solution for packing.

3.18.1   Profitability in Production Processes

Profitability in production processes can vary much as it is often human operators in the processes, making the calculations harder. Profitability and production efficiency relates to each other and making production more efficient often leads to profitable development. However, to specify profitability in production there are different aspects to cover, such as lead times, quality, takt times, down time, human operators and efficient use of machines to name a few [23]. Many factors affecting the profitability is closely linked to time consumption for different actions. Lean manufacturing is also driven by increasing profitability, but rather to focus entirely on time or profitability. Lean focuses on waste or value, which aims to increase profitability by reducing wasteful operations [23]. Profitability can be achieved by cost avoidance, investment or long term planning of production processes and resource use [24].

Cost of personnel is a big cost in production [23]. In Sweden during 2022 was the mean salary of an operator 227,20 SEK per hour and median salary 230 SEK per hour [30].

3.18.2   Profitability in Shipping

Shipping and logistics is a very broad industry affecting every organization in the world. To calculate shipping profitability there is need to limit the scope, and focus on what is important in this project, packaging and more importantly how many packages you can fit into one transport unit. Furthermore, safety is a very important aspect as working environment can be stressful, exhausting and also be dealing with heavy and dangerous goods [12]. Following areas are important when determining profitability:

24

- Payload

- Space optimization

- Safety

- Cost avoidance

Payload is the maximum mass that is permitted to be loaded into a transport unit [31]. Payload has a big influence on different aspects, such as revenue and profitability but also how it is loaded at port [32]. It determines how much can be loaded, which influence how it should be loaded because of need to spread the load evenly over the container and CTU [8].

Space optimization is another aspect that needs to be considered for profitability in shipping. When shipping products the cost is determined by the volume of the package that should be shipped. To minimize the packages footprint in a container can save organizations money but will also improve sustainability. Space optimization can be achieved by optimizing the package around the product, but also by enabling packages to be stacked. This is to fully utilize the space, in all directions. Considering sizes of packages there are standardized pallets and packages used worldwide today, see chapter 3.5, but also standardized container sizes, see chapter 3.3, and these are used to optimize space. If all organizations where to use different sizes in pallets, packages and containers it would make it hard to reach a good space utilization. However, still there are different pallet sizes used in different continents.

Safety is also closely linked with profitability which is due to the cost of handling problems in the value chain [8]. Foremost it is about human safety, and having a safe working environment for the operators handling the shipping but also the package, in factory, at end-user and during shipping. Human cost is invaluable and cannot be specified in numbers. However, keeping a package safe during its life stages is important to reduce risk of damages, to either the cargo or the environment. Penalty fees can be issued if a package is poorly built and causing damage to either the cargo transport unit or surrounding environment. If a package is damaged it could also lead to repackaging or even sending the package back to be repacked and possible repairs carried out on the damaged goods. Leading to lower customer satisfaction, more delays to customer and increased shipping costs.

Cost avoidance is also an important aspect, related to space optimization and profitability [33]. In logistics this is desirable, as the package is needed but is a cost for the organization. Because of this, the focus is on avoiding cost rather than earning money on the transportation. If it is possible to stack more products into one container, it will cost less than splitting the products on two containers.

3.19 Sustainability

Four different areas are identified if a package is deemed sustainable: effective, efficient, cyclic and safe [34]. Effectiveness is specified as the package's ability to perform functions specified a package should do. Efficient packaging focuses on the impact it has on the environment, such as use of resources. Where material use is an important area. It is a critical aspect regarding sustainability as there are multiple parameters that affect a products performance depending on its material [35]. Material use is affected by design choices and by the designers experience and biases, even though a rational approach is preferable it is not possible due to the amount of information needed. However, design choices have the possibility to reduce use of materials.

Cyclic package is the potential to use the package again, either re-used, recycled, downcycled or remanufactured for example. Lewis [34] is focusing primarily on recovery optimization of materials, energy and water. The safety aspect focuses on human and environmental risks when using the package.

4 Method

This chapter covers the methods and how they are applied in this project. As this project focuses on production and product development, the methods influence each other. Data gathering and analysis regarding production supports building target specifications and knowledge about the product development.

Figure 11 shows how the two areas of product development and production development is conducted in parallel. During the project they are influencing each other.
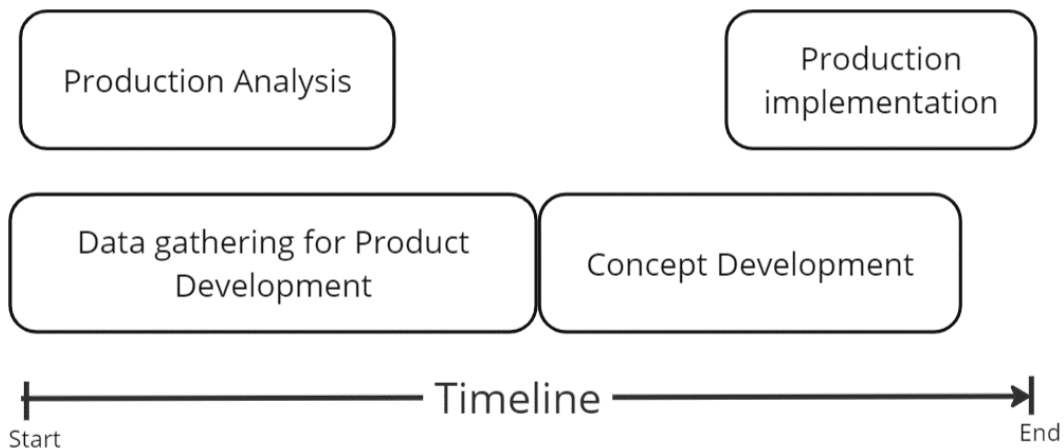
Figure 11: Overview how the different areas of methods is conducted during the project.

4.1 Product Development Methods

It is necessary to analyze if the method of choice is relevant and if there are any need for adjustments. First is the methods presented, and their advantages and disadvantages, before a product development process is concluded in chapter 4.2.

4.1.1 Ulrich and Eppinger's Product Development Method

Ulrich and Eppinger's product development method, see chapter 3.6, is a bit modified in this project. As the aim of the project is to generate a concept, the method is only applicable to the fourth step, *select product concepts*. The method emphasizes development of target specification and specify those to facilitate comparability between current state and how the solution improves that situation and fulfill customer needs. However, the method is, during data gathering and development of target specification, separated from possible solutions. This is restricting the creative process and iterations of ideas during the development process. Furthermore, this project has focus on production processes and functions which are not taken into consideration for the development process naturally in this method.

27

The workflow of Ulrich and Eppinger is logical and will be applied, but complemented with parallel methods and processes for further understanding of the problem and possible solutions.

4.1.2 Liedholm's Systematic Concept Development

Liedholm's systematic concept development process is going to complement Ulrich and Eppinger's product development method in this project. Liedholm's method is considering possible solutions early in the process of developing a concept, which can be seen when developing technical principles. Applied in this project, the development of these principles further the understanding of demands and investigate possible solutions early on, which suits this project. With Liedholm's proposal of schematic views of the functions and principles, a structure and visualization of the process is applied to the project which is beneficial when working alone.

4.1.3 Ullman's Design Process and Product Discovery

Ullman's design process is implemented sporadically in the project, because of some the validations he proposes. The iterative philosophy of developing target specifications and concept generation is beneficial when development is conducted by a single person, it makes room for continuous reflection during the project.

4.2 Product Development Method in this Project

This project follows a modified product development method, based by Ulrich and Eppinger's method. The framework from Ulrich and Eppinger is used, but include parts from Liedholm's and Ullman's design processes and methods. This is done because of the focus on production processes and improvement in this project. However, the aim is to present a concept of a design, or product, to fulfill the goals which creates the need of a product development method. Furthermore, Ullman's approval suggestions is included to keep stakeholders informed and in the decision loop. Which ensures that the result meets expectations and fulfills the goals.

The method used can be seen in figure 12 and are the framework of how the product development process is concluded. It combines analysis from Ulrich and Eppinger with Liedholm to cover multiple perspectives on product development, and the processes influenced by it. Ullman's approval suggestion is used to ensure that the work up until that point follows the objectives of the project and that enough time is available for the continuation. As seen in figure 12, the processes are not sequential, but parallel and will influence each other.
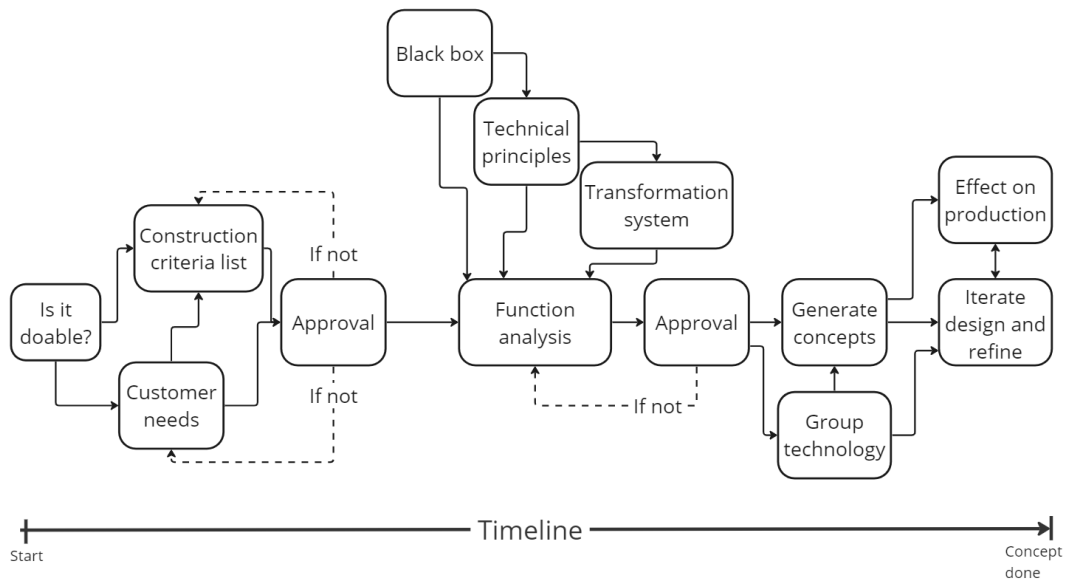
Figure 12: Ulrich and Eppinger, Liedholm and Ullman's processes combined to suit this project.

4.3   Product Development

Following the process presented in section 4.2, and answering the question, *is it doable?* This project needs limits, as it has potential to grow out of the scope. If delimitations is not determined, it could risk the project to be left unfinished. However, is it doable? Yes, but there is a need for suitable delimitations. To establish delimitations, an understanding of the problem is necessary, which is done during the project parallel to establishment of methods, goals and scope.

4.3.1   Customer Needs

Customer needs are gathered from different sources and data gathering methods. The first method is to getting hands on experience with the current process and starting to build knowledge about the challenges. Experience the setting where the concept developed will be deployed is valuable when starting to develop the needs of the product. Furthermore, in that setting, it is favourable learning how to handle products, but also to establish relationship with the operators makes future communication easier. During this stage there are a lot of new impressions and a need to gather and structure the information given. This is done in two steps, first is notes which is then translated into more detailed and structured statements that holds any information deemed relevant. This information comes from the experience working, and informal and unstructured interviews with the operators. The structured notes are later translated into the customer needs list.

Further development of the customer needs is performed in a more structured way. Where the information is gathered during interviews with people which potentially will be affected by the project and people with expert knowledge in relevant areas. The interviews are split into two different areas, interviews with experienced operators and interviews with managers. The two perspectives give a thorough insight

into the different areas and how they may be affected, but primarily what the challenges are in their area connected to the project. The interviews with both areas is unstructured to facilitate discussion, primarily due to the limited knowledge of the area and of the project at this stage. The answers, *customer statements*, are gathered, analyzed and rewritten into the customer needs table. As the knowledge about the challenges and the project increases, the interviews are getting more detailed and technical, uncovering more information. Furthermore, it uncovers hidden needs, where a need is not articulated but indirectly communicated.

However, the customer needs is not developed exclusive from interviews with people. According to the research questions and the area of the project there is a need to gather information and knowledge about the industry. Different industries have different standards, regulations and guidelines that needs to be followed for a successful result. This needs to be analyzed and presented as customer needs due to its importance to the project and the limiting effect it will have if not followed.

4.3.2 Design Criteria List

As the aim is to produce a product development process focusing on production performance the design criteria list includes several important steps. This list have similarities with the customer needs and are because of this partly performed parallel. The design criteria list is developed to answer different questions from a checklist given by Liedholm. They cover important areas of the product and its area of use, the check list can be seen in Appendix 12.

4.3.3 Target Specification

Target specification is constructed partly from the customer needs according to Ulrich and Eppinger's method, but also includes a broader perspective. Including elements from the design criteria list, such as legislation and regulations affecting the product. The customer needs are interpreted and analyzed to achieve the target specification, the needs are translated into targets and thus some of the needs may fall under one target. The target is developed to be measurable, facilitating comparison with competitors or between design iterations. The document of target specifications is be seen as a document that is alive and be updated when new information arises.

4.3.4 Function Analysis

An analysis of what functional abilities the solution must consist of is conducted. This is done to ensure a good understanding of what direction the project should be moving and what is needed to achieve set goals. Function analysis is split into three different processes which all make use of the gathered data up until this point. These processes are black box, section 4.3.5, technical principles, section 4.3.6, and transformation system, section 4.3.7.

4.3.5 Black Box

A black box is created to broadly visualize the main goals of a product development method. Which ensures a broad understanding of the product development and how to solve the challenge. The black box is the foundation, what should be achieved and processes to reach there. Furthermore, it specifies the main objective of the solution, see section 3.7.2 and figure 8 for reference.

The operand, is what needs to be converted, from one state to another. Its function is the black box, which is defined very general to not predetermine any solutions, or remove any possible functions that may interesting.

4.3.6 Technical Principles

The technical principles is used to understand the targets, limitations and possibilities of the project. The functions are generalized to include all targets, customer needs and design criteria. The functions work as a tool when looking for possible solutions for each function, like a framework for brainstorming. The technical principles achieves a comparison with the current market at the same time it is looking for innovative ideas for the essential functions for the product. The technical principles are developed different compared to what Liedholm advocates for. Where it is used to include customer needs and targets and to use that to help the creative process with possible solutions. This is done without creating the visual aid and tree that Liedholm does in his literature. In the table that develops the technical principles consists of solutions already on the market but also new creative solutions. It creates a network of solutions to subfunctions which later in the process can be combined to a product or concept.

4.3.7 Transformation System

The transformation system is used to understand the effect of the product and the overall system needed for the use of the product. It includes, for the technical principles, a transformation system that shows which entities are affected by the implementation of the product and its functions. However, the technical principles are designed in a slightly different way, creating the need to do the transformation system slightly different compared to the theory. Instead of doing a transformation system for every technical principle, the transformation system is developed more broadly. Each function has a specific operand, and that operand is using either of the systems, *human operator, technical system or active environment.* Defined is which operand and system is included in that specific function, and what phase that function is connected to. It is important the keep distant from possible solutions or how it is today and define the functions generally to not make the solutions biased towards current solution or how the market looks today. This is done by using the general functions developed in the technical principles and determine the operands for each and how they are connected to the different systems.

4.4   Group technology - Product Development

Group technology applies to gather information about similarities of products, and apply this knowledge to the product development phase. This applies where similarities are needed to support the product development and are not used exclusive in certain stages of the product development. Group technology has potential to support product development, if a product needs to suit functions with high variation, or the product is dependent on other products and functions, they too with high variation. If the functions or products affecting the developed product can be grouped and categorized where relevant similarities exists for the product development, it may reduce the variation for the developed product. Hence, group technology is applied differently from its theoretical use, where it is more focused on production and a line balancing perspective. It has however the same purpose, reducing variations which is helpful when trying to solve a problem consisting of high variation products.

4.5   Design Evaluation

When the concept has been developed, it needs to be evaluated according to certain parameters. What parameters that needs to be evaluated is specified during the product development phase, where the targets are created. The different parameters leads to different analysis regarding the concepts performance. If different concepts exist they compares according to their performance of the important parameters. The comparison between the concept can follow different methods. However, the aspect to consider is if the concept developed fulfills the targets. As the targets are derived from customer needs, regulations and legislation it is important that the concept fulfills these targets to have potential for success.

Durability of the design is one example of how the design could be evaluated. Where, depending on the targets, a calculation is made to verify the integrity of the design elements when subject to loads. This example can be calculated by stress, strain or strength to give a few aspects that can be considered during the evaluation.

4.6   Production Analysis Methods

This section covers the methods applied to analyze the production and as a tool to estimate effect of the concept on production.

4.6.1   Value Stream Mapping

A value stream mapping is conducted to identify processes and flow of information and material in the factory. To fulfill the requirement for the value stream mapping of having broad knowledge about all operations, the mapping is limited to focus on the delivery station. This is done to ensure a relevant and correct value stream mapping is developed. Furthermore, the mapping is done in two stages of the project, first to understand the current state of operations. Second, revised mapping after concept generation where an estimation of the impact on production of the concept is visualized.

Value stream mapping identifies value- and waste streams and creates a baseline which the developed solution will be compared against. The mapping also visualizes what steps which can possibly be removed, and/or needs to be added to have the concept working in the production. The mapping supports further analysis of the production system, with the gathered data and identified waste- and value streams.

4.6.2 Internal Logistics

Using the different methods explained in the theory chapter, see chapter 3.11.2, to analyze and suggest internal logistics when the new concept is developed. How should this be deployed in most efficient manner is the question to answer. First an analysis of the concept developed is needed to be able to determine which parts have what functions and where in the process they are needed. This analysis covers how the parts of the product flows through the factory and at what stations they need to be at to reach an efficient way of working. In combination with the revised value stream mapping and line balancing, the actions needed to assemble the package is specified. The actions, and the order of them tells the story of how the parts of the package is delivered to certain stations in the factory, and how they are being assembled.

4.6.3 Group Technology

This manufacturing philosophy is used in this project in two ways, to support product development, as mentioned in chapter 4.4, and to categorize the products for understanding how the processes should be balanced. It is applied as a tool to help production by categorize the products, and how they should be used with the developed concept. Which products suits which configuration of production methods, machines or products used in production.

This project is focused on packaging and its role in production, hence a focus on the products from a packaging perspective is relevant. Categorizing the products depending on demands on transport, packages and packaging methods will ensure that the implementation into production will be smooth. The categories can show operators and people planning production what products needs what and with that knowledge, take informed decisions. Overall, uncertainties are removed and challenges with a big variation of products are narrowed to a smaller amount of categories which needs to consider.

4.7 Profitability and Sustainability Analysis

Profitability is calculated from a time consumption perspective. The main focus on profitability is finding ways to improve production, and primarily time consumption. But also finding ways for the organization to create a potential output from the factory, enabling growth of sales. Time is the main driver for profitability in this project, where the current state is compared to the proposed way of working.

Time consumption regarding packages and packaging is documented and is where the comparison is made. Calculations of cost in production is an aspect to consider if such data exists, otherwise it is outside of the scope of the project.

5 Pre-Study

To facilitate comparability and development there is a need to understand current state of operations. As stated in delimitations, see section 1.7, the focus of this project is on their delivery station primarily, but with a open mind looking for possibilities elsewhere. The value stream mapping for the delivery station gives an understanding of material-, product- and information flow. Furthermore, it gives a possibility to understand where potential are to enhance performance.

5.1 The Pumps

Focus of this project is on the VASA-line of pumps that Metso produces, these pumps are primarily manufactured and produced at the Sala site. The pumps are primarily sold within Europe and the CTU is often on road, there are however pumps that needs to be shipped over sea. The pump has a lot of different parts, not all with relevance to this project. This chapter covers the important parts of the pump for the project. See figure 13 for reference.

- **A: Pump house:** The pump house is the cover of the impeller and this casing also has a big effect on the pump performance due to its internal geometry.

- **B: Frame:** The frame is the support structure where the pump lies, and its size is dependent on which pump that should be assembled.

- **C: Shaft:** This shaft has the bearings mounted on it and affect the size of the overall pump due to it sticking out.

The three parts are the parameters which are deciding size when packing a pump. But all three are connected to certain pump models, and the modular sales catalog Metso offers has little effect on the final size of the product, as most of the modularity is inside the pump. However, the weight and centre of gravity of a pump can differ for the same model of pump between two orders.
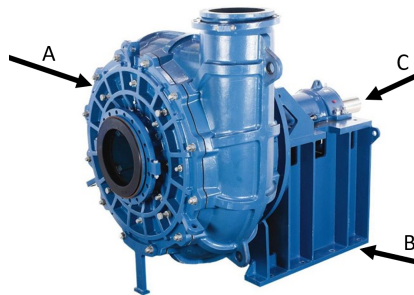
Figure 13: A VASA pump and its important parts for this project.

A simplified process is presented in figure 14, to illustrate how the pump is moving through the factory. The packaging is done at the delivery station, and every operation before is to either prepare for assembly or assemble the pump. Before the assembly of the pump is done, the pump parts moves to the kitting station, where the parts for the pump are gathered and structured for the operators at the pump assembly station. The parts arrive to the kitting station from the local storage, and

the assembly station for shaft and bearing. When the parts arrive to the pump assembly station, they are placed on EPAL1-pallets. Depending on the size of the pump, a EPAL1-pallet is where the pump is placed on during assembly. Before the pump assembly finishes it moves through a simplified pump test, testing the pumps performance. After that test, the pumps moves back to the pump assembly station to be finalized. When pump assembly is done, the pumps moves to one of three different places: Local storage, delivery station or buffer area for the delivery station. When the delivery station has possibility to receive pumps, and the pump is not to be stored, the delivery station get the pump delivered. The pallet used during kitting and assembly is now not used anymore, but the pump is moved to another pallet. The same with the support structure used in pump assembly, is changed to another support structure for the shipping.
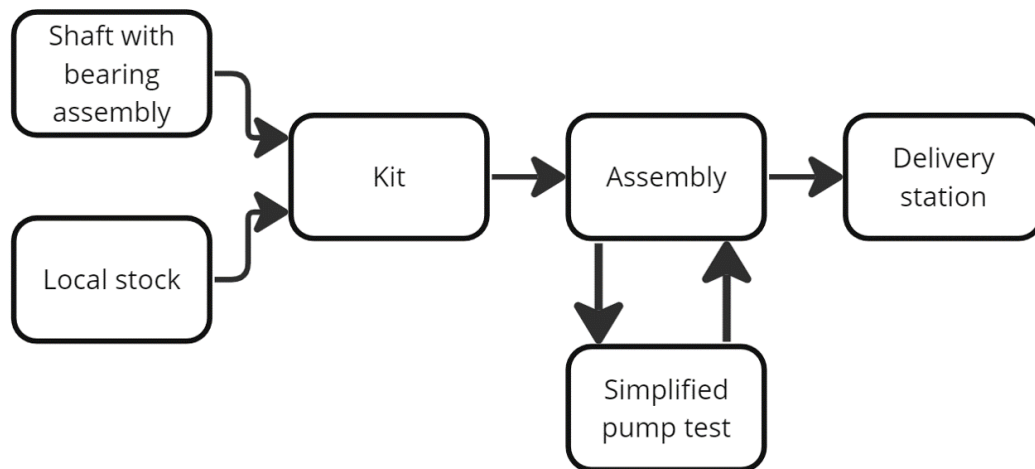
Figure 14: Simplified flowchart of the pumps through the factory.

5.2   The Package

The packages that are being custom built are not verified or validated, except for using wood following ISPM-15, see chapter 3.5.3. It is necessary to split current packages into two different groups, packages using EU-pallets and packages with custom built pallets. As stated in chapter 3.5.2, the EU-pallets have a limitation on an even load distribution of a maximal 1,500 kg, which make this pallet not safe to use for a majority of VASA-pumps. Not necessarily due to their weight, but the distribution of loads on the pallet.

There is no data regarding problems with packages at end-users today, but problems have occurred on site, indicating a need to verify the package capabilities. It is also suggested that unreported problems are occurring due to the problems internally, but no such reports have been received.

5.3 The Processes

Starting the process of building a package is the notice that a pump is delivered to the delivery station and a order from planning, detailing when it should be dispatched. When a pump is arriving to the delivery station an operator is measuring the pump and starting to build a package for it. See figure 15 to understand how the package can look. In this example, it is only needed to build and assemble the top and one of the short sides for the package.

Figure 15: Showing how a package and the pump looks while a package is being built.

Building a package for a pump is a sequential process, where no parallel activities occur. And the information flow is a push system, where the information about what pump to pack is given to the operators when the pump arrives to the delivery station. Building the package is done by one operator, and every action is noted in figures 16-18. The figures specifies:

- **Time consumption:** Every task has been clocked and specified.

- **Description of task:** What the operator does.

- **Task preceded:** What task that needs to be finalized before starting with a certain task.

- **Change over time (CT):** How long time it takes for an operator to do necessary actions between the tasks, e.g. change tools or gather material.

- **Total time:** This is the total time consumption for that specific task.

- **Operation:** Categorized tasks into operations to more easily present time consumption, waste and value adding activities.

- **Waste, auxiliary or value adding action:** If the task that the operator perform is waste, and should be removed, or value adding to the package.

No	Work element description	Time [min]	Perceeded by	CT	Total time		[min]	Type of Op
1	Fetch pump	5	-		5	Op 1		Waste
2	Measure pump	4	-		4		9	Waste
3	Gather wood	1,5	2	0,2	1,7			Waste
4	Saw wood into correct lengths for pallet	2,5	3	0,1	2,6			Value adding
5	Construct beams to the bottom of pallet	4	4		4			Value adding
6	Nail wooden planks onto beams	4	5	0,1	4,1			Value adding
7	Measure distance for the last wooden plank	0,5	6		0,5	Op 2		Waste
8	Gather wood	0,5	2	0,2	0,7			Waste
9	Saw it into correct width & length	2	8	2	4			Value adding
10	Dispose of not used wood	0,3	9		0,3			Waste
11	Nail last wooden plank into place	0,5	9	0,3	0,8			Value adding
12	Lift pallet down onto the floor	0,5	11		0,5		19,2	Auxiliary
13	Lift up pump and place it over pallet	5	12	0,4	5,4	Op 3	5,4	*Value adding*
14	Measure pump and pallet to know support strucutre geometry	4		0,2	4,2			Waste
15	Saw wood into correct lengths for support strucutre	6		0,3	6,3	Op 4		Value adding
16	Dispose of not used wood	0,3	15		0,3			Waste
17	Nail wooden planks into support structure	4	15	0,3	4,3			Value adding
18	Place pump onto pallet with support structure	2	17	0,2	2,2		18%	Auxiliary
19	Make sure it fits	1	18		1		18,3	Auxiliary

Figure 16: Action list for building a package to a pump. This explains different operations, their time consumption and what actions that each action must be preceded by. CT stands for change over time, and op stands for operation which is categorized actions.

No	Work element description	Time [min]	Perceeded by	CT	Total time		[min]	Type of Op
20	Put plastic onto pump	2	18	0,2	2,2			Value adding
21	Tape plastic in place	0,5	20	0,2	0,7	Op 5	5%	Value adding
22	Put more plastic on pump	2	21	0,4	2,4		5,3	Value adding
23	Gather wood for the sides of the package	2	-	0,5	2,5			Waste
24	Saw wood into correct length of the package	2	-	0,3	2,3			Value adding
25	Dispose of not used wood	0,3	24		0,3			Waste
26	Nail wooden planks for the sides of the package	2	24	0,3	2,3			Value adding
27	Measure distance for the last wooden plank	0,5	26		0,5	Op 6		Waste
28	Gather wood	0,2	-	0,2	0,4			Waste
29	Saw wood into correct length and width	0,4	27	1	1,4			Value adding
30	Nail the last wooden plank onto the side	0,5	29	0,2	0,7			Value adding
31	Put plastic onto the side	0,7	30	0,2	0,9		13%	Value adding
32	Mount side onto pallet	2	31		2		13,3	Value adding
33	Gather wood for the sides of the package	2	-	0,5	2,5			Waste
34	Saw wood into correct length of the package	2	-	0,3	2,3			Value adding
35	Dispose of not used wood	0,3	34		0,3			Waste
36	Nail wooden planks for the sides of the package	2	34	0,3	2,3			Value adding
37	Measure distance for the last wooden plank	0,5	36		0,5	Op 7		Waste
38	Gather wood	0,2	-	0,2	0,4			Waste
39	Saw wood into correct length and width	0,4	37	1	1,4	Build sides		Value adding
40	Nail the last wooden plank onto the side	0,5	39	0,2	0,7			Value adding
41	Put plastic onto the side	0,7	40	0,2	0,9		13%	Value adding
42	Mount side onto pallet	2	41	0,2	2,2		13,5	Value adding

Figure 17: Continuation of action list for building a package to a pump.

No	Work element description	Time [min]	Perceeded by	CT	Total time		[min]	Type of Op
43	Gather wood for the top of the package	2		0,5	2,5			Waste
44	Saw wood into correct length of the package	2		0,3	2,3			Value adding
45	Dispose of not used wood	0,3			0,3			Waste
46	Nail wooden planks for the top of the package	2		0,3	2,3			Value adding
47	Measure distance for the last wooden plank	0,5			0,5	Op 8		Waste
48	Gather wood	0,2		0,2	0,4			Waste
49	Saw wood into correct length and width	0,4		1	1,4			Value adding
50	Nail the last wooden plank onto the top	0,5		0,2	0,7			Value adding
51	Put plastic onto the top	0,7		0,2	0,9		13%	Value adding
52	Mount top onto pallet	2		0,2	2,2		13,5	Value adding
53	Finalize packaging	4		1,5	5,5	Op 9	5,5	Auxiliary

Figure 18: Continuation of action list for building a package to a pump.

The action list is analyzed by a few equations to specify where the issues are. And equation 6 shows that 15,7 percentage of all available time for one operator is spent on wasteful operations. Equation 7 shows current spending on wasteful operations for one operator over a year, which amounts to 225 000 SEK. where the cost is calculated the mean salary for employed people in metal industry in Sweden during 2022 [30], and total cost at Verksamt [36].

$$Waste_{fraction} = (Waste \cdot Pump_{total}) \frac{T_{available}}{T_{workdays}} = 15.7\% \qquad (6)$$

$$Cost_{waste} = Salary_{mean} \cdot Waste_{fraction} = 225\ 000\ SEK/year \qquad (7)$$

Material use and cost of personnel is the parameters that is being considered during this calculations. And this is leading to annual loss due to waste of seven percent of total investment. Material use is primarily the wood that is used to build the packages. Around 10 percent of the purchased wood is estimated to becoming waste.

Figure 19 shows a summary of the action list, and the fraction of wasteful, value adding and auxiliary operations during the handling and building of the package.

N.o. operations	% of waste/value operations	Amount of time		
19	35,8%	23,8	23,1%	of total time is spent on waste operations
29	54,7%	66	64,1%	of total time is spent on value adding operations
4	7,5%	9,2	9%	of total time is spent on auxiliary operations

Figure 19: Summary of actions list.

The action list shows that 35.8 percent of the operations is wasteful, and can be removed. The wasteful operations represent 23.8 minutes, or 23.1 percent of total time handling the package per pump delivered. The action list also shows that building the package covers 69 percent of the total time it takes to pack the pump, excluding actions like fetch the pump and register that the package is done. Continuation of analyzing the production and packing is done by value stream mapping, see figure 20 which shows the material and information flow through the factory with a focus on the packing station.
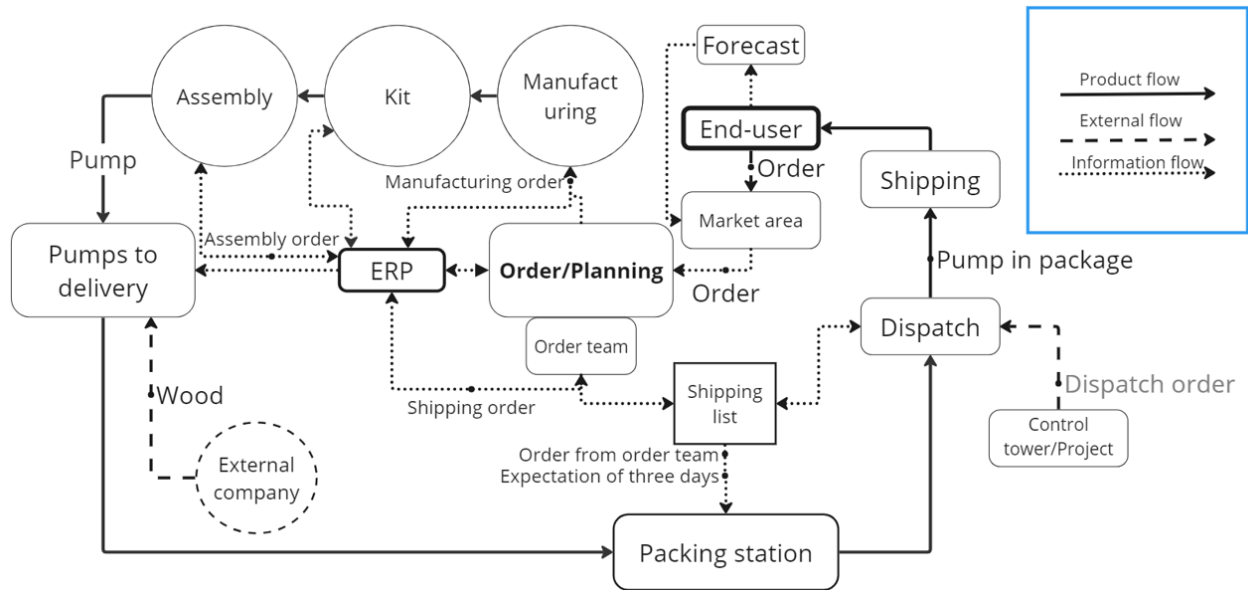
Figure 20: Value stream mapping overview of the factory with a focus on the delivery station.

As the delivery station is where the package is currently built, it gets a big focus and therefore a more detailed mapping. The delivery station in figure 21 is a detailed view of the *delivery station* in figure 20. As seen in the overview of the value stream mapping, there is an expectation that the process from assembly to dispatch will take three days, but are depending on the type of pump.
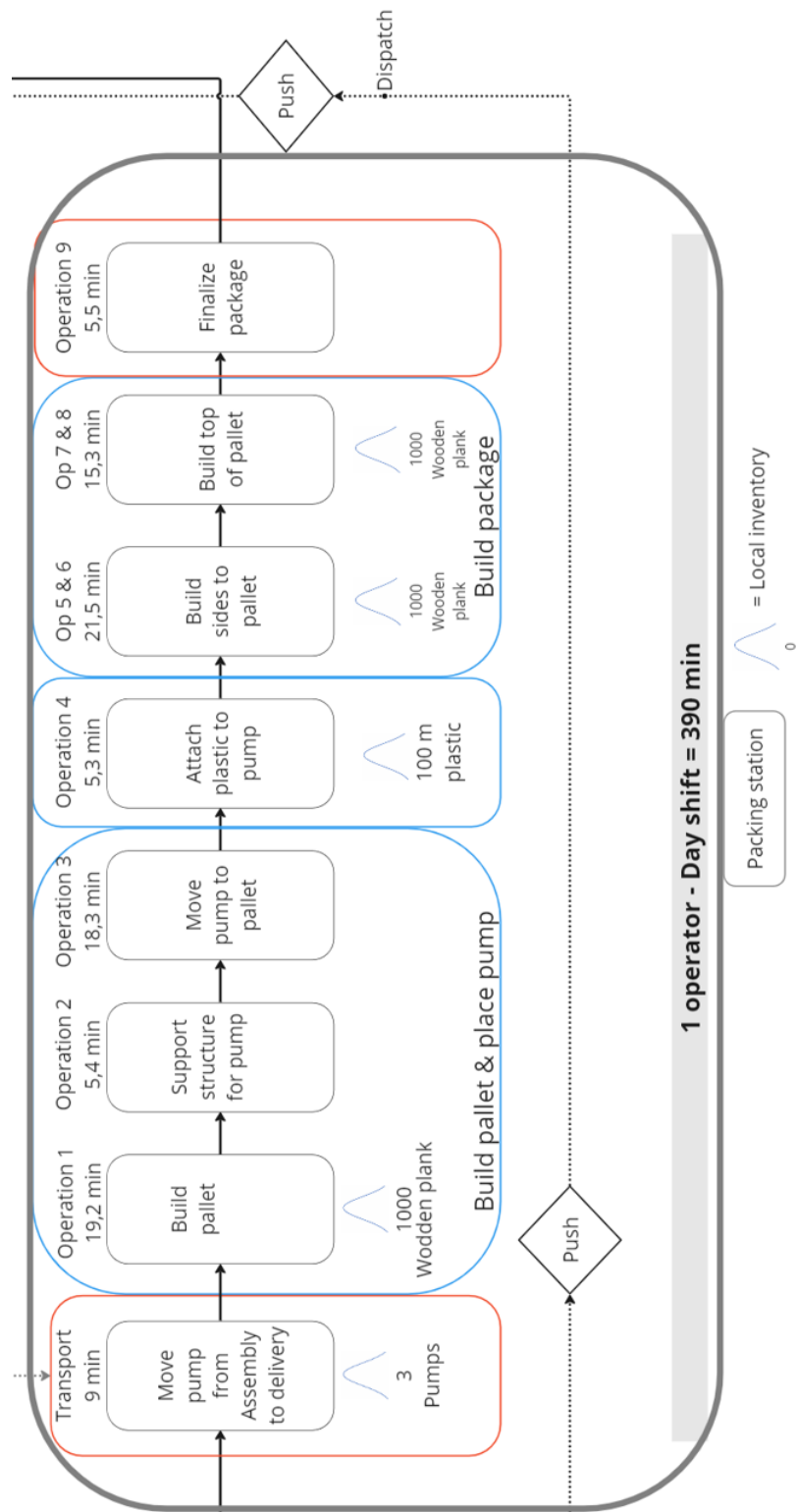
Figure 21: Shows the operations in the delivery station for a specific pump. Inventory level, time consumption, change-over time, information flow, product flow and available time for one operator is given in the figure.

Figure 21 shows that the local stock at the packing station is very large, both for pumps and wood. The pumps stored at the packing station are pumps which could be packed, if the resources and conditions where there to pack them. Now the pumps have to wait for other pumps being packed, making them stand still in production. Another interesting part is the linear work flow, where if operations would be performed in parallel, the time it takes can be reduced drastically.

Figures 16-18 specify all the actions and in what order the actions must be performed. This list is constructed as a line balancing list, with addition of waste- and value adding actions. Note that the wasteful actions can be removed. This list is, combined with the VSM, providing a good understanding of how to current situation is at the delivery station today.

5.4 Identified Areas of Interest

During the analysis of the current state of the production and packaging multiple areas of interest is discovered, which is what are presented in this chapter. Primarily, the information flow through the factory, where the building of the package does not start until the pump arrives at the packing station. It is increasing risk of bottlenecks in the packing area. This setup causes the packing station to be badly prepared for spikes in demand, where the station will follow the momentarily demand at the packing station, not considering the demand on overall production. It causes delays when the demand increases, contributing to a lag effect when the demand lowers again, affecting more pumps, see figure 22.
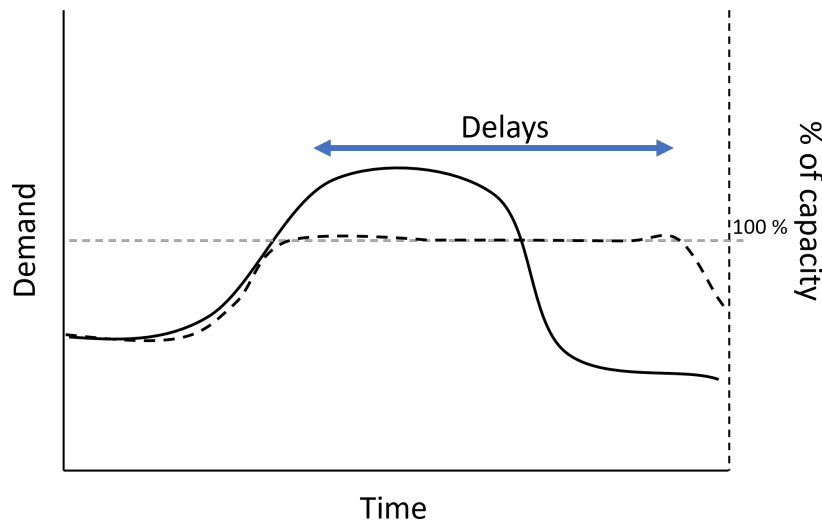
Figure 22: Visualization of how spikes in demand is creating a lag effect before the packaging station's capacity is under 100 percent again.

Building the package is another area of interest. Building one package take relatively long time, and is measured to be 112,5 min, thus creating a limit of how many pumps can be delivered from the factory. Which is 866 pumps per year. However, from conversations with operators they estimate time consumption between two to six hours per custom built package. Even though recruiting more people could re-

duce time, see appendix 12 figure 42, it is a question about space. It is not possible with today's setup to increase the output from the package station without rearrangements of machines, tools or other stations. There is a need, as the aim is to increase output from the factory, to make the packing station more efficient.

The action list is uncovering waste streams within the delivery station, which accounts for 23,1 percentage of the time it takes to build a pump and 31,4 percentage of the operations is waste. For example, if half of the pumps delivered from the factory in Sala are built like this it would count up to 15,7 percentage of an operators total time working over a year. This is an estimation, the time it takes differs between the pump models, operator responsible and daily differences. The variation of pumps makes it hard to gather validated data without the risk of incorporate errors in that data set.

How the information flows through the factory is a push system. An operator sees the pump being delivered to their station, and starts to measure it to start building the package. In rare instances, during higher volume sales of one pump model some parts of the package can be pre-built. Information about time it takes to assemble a package for a pump is limited. Currently the planning organization is estimating that from assembly is finalized it takes between three days to a week to deliver the pump.

Currently the package is designed by experienced workers who know what demands the packages needs, but no standards or routines exists. Leading to a person-dependant organization which is vulnerable to losing an operator, even for a few days. This is also problematic regarding legal matters, where the package should be verified and tested to know which loads it can endure.

When the pump is assembled it is done on pallets with temporarily support structure for the pump. As the VASA-pumps has eccentric centre of gravity it is prone to tilting and falling if not properly fixated on the pallet, causing safety hazards.

5.5   Safety Risks

Current solution has problems regarding safety and is not verified to hold up to the weight or the international standards. Safety risks identified is:

- **Nailgun:** Assembly of the packages today is mainly done with the help of a nailgun, which creates a risky environment. The nailgun also creates a very loud working environment for the operator.

- **Ergonomics:** Lifting the pallet and sides of the package when assembled can be cumbersome and heavy, stressing the body of the operator. Add a stressful work environment and it is a big risk of taking a shortcut, injuring themselves. If an items weight is above 20 kg, it is required for an operator to use lifting aid to not get hurt.

- **Handling pump:** The pumps weighs very differently and handling the very heavy pumps, even with a crane increases the risk of getting injured. The

centre of gravity is often eccentric, creating unbalanced packages and safety risks when handling.

- **Not verified solution:** As today's solution is not verified, it is impossible to know if the package will hold up to the different loads and stresses during transport.

- **Damaged package:** When the end-user receive the package, and the package has been damaged during transport, there is a big risk of injury when handling the package.

- **Tilting risk:** Related to handling of pump but a specific problem is the tilting risk of VASA and VASA HD pumps which has an eccentric centre of gravity.

6 Product Development

This chapter covers the results from the product development, from feasibility to requirements.

6.1 Is it doable?

As the project was issued before the project start, the analysis that needs to be performed is the limitations for the project. Limitations are fluent as more knowledge and challenges arises during the project and this list needs to be updated accordingly. There are a lot of areas within Metso covered and affected by the project, such as planning, logistics, research and development, assembly and purchase. Leading to the project in need of limitations to have the potential to be finalized. The limitations are developed during the project, but during this phase it is important to see what should be delivered, to determine feasibility of the project. Data is gathered and scope of the project is limited to focus on the site in Sala and on the packaging station in Metso's factory.

6.2 Customer Needs

Customer needs are developed according to the presented method in chapter 3.6.1. This information is gathered by doing unstructured interviews with stakeholders and users of the current product or in current setting. External customer needs have also been gathered from international standards and regulation, which is also stated during the interviews. Customers identifies as internal customer and external customers, where the majority of people asked are internal customers. The design criteria list is developed parallel to when the customer needs is gathered, and inspiration is taken from the design criteria list regarding which questions were going to be asked.

The customer needs are presented in table 7 and some of the needs interpreted is regarding the production aspect, and some of the functions of the product.

Table 7: The customer statements and how they are interpreted as needs.

Customer Statement	Interpreted need
A big variation in pumps	Needs to suit a big variation of pumps
The pumps can be very heavy	Needs to handle heavy loads
Package can be hard to handle for one operator	Needs to be easy to assemble
Wood is hard to store close to packing station	Needs work instructions and a material flow
High peaks in demand creates a stressful work environment	Needs to increase efficiency at packing station
Pump tolerances can cause fitting problems	Needs to have enough clearance to suit possible variations
Uses a lot of material	Needs to optimize material use
Hard to know exactly where centre of gravity is	Needs to be specified where centre of gravity is
A few people know how to build a suitable package for different pumps	Needs to standardize packages to reduce dependency on people.
Support structure does not always fit the pump design making it unstable	Needs to standardize support structure
Can be hard to move with truck	Needs to be truck compatible
Sometimes hard to load efficiently in transportation mode	Needs to suit standard transportation storage (e.g. containers)
Some packages are not accepted at ports occasionally	Needs to follow international standards and legislation (e.g. ISPM-15)
Pump are occasionally damaged during transport	Needs to fully secure and make sure no harm is done to pump
Pumps have tendency to glide off pallet during transport	Needs to fixture pump to avoid movement
Pumps are susceptible to corrosion	Needs to protect the pumps from corrosion
Tilting the pallet sometimes cause the pump to fall	Needs to fixate the pump making it possible to tilt the pallet without having the pump falling off
End-users sometimes lift the package in the wrong way, causing safety issues	Needs to have a design that requires operators to use it in the correct way

The customer needs are gathered and interpreted to create a structure, where the statement of the customer is interpreted as a need for the solution. Some of the interpreted needs are closely linked, but eventual categorization is done in later stages.

6.3 Design Criteria List

The interviews in customer needs inspires the design criteria list. The list includes important functions that the concept should have. It is split into different phases of the life cycle, and different areas which affects the development of a package. Different areas of focus are presented with different factors which influence further development of the concept. For each area different criteria is presented.

Table 8: Design criteria list for the package.

Delivery and planning	Package is needed for every sold pump	Package is needed to be produced when an order is received		
Safety Abilities	It needs to be easy to access with lifting equipment	It needs to bear the weight of all products	It needs suitable and correct labeling for ease of use	It should be able to tilt the package and not have the pump falling off
Aesthetic	It is the package received by end-user so it needs to look good	No need to follow trends for package		
Legislation	It needs to follow international shipping legislation regarding safety	Needs to fulfill standards used by shipping companies globally	Needs to fulfill standards used globally regarding material of packages	It has a risk of using patented solutions
Economic	Manufacturing cost should be minimized as the package is only used once	Operating cost of the package will be determined in efficiency gains because of package	Cost of end-of-life treatment will not be considered	
End-of-life	It can be re-used but it is designed for a specific purpose	When recycling parts should be separated	Package is going to be disassembled when arriving to end-user	
Ecological	What materials to use needs to be considered to be as sustainable as possible	No hazardous substances should be used		

Abilities	Purpose is to guard both the product and environment.	It should be liftable	It should be easy to assemble product onto package			
Function	It needs to bear the weight of all products	Some lifting tool should be able to lift the package with the product on it	All different pump sizes should be able to fit onto the package	Sides should protect the environment from the content		
During use	Used in varied environments, production, shipping and at end-customer	It will be used for intended purpose one time, but time can have big variation	The package's lifetime is from assembly of pump to delivery to end-user	Maintenance will not be possible after delivery from production site	No changeable parts	Fixating points needs to be easy accessible
Manu-facturing	Product could be manufactured at current site, but also out-sourced	No new machines are needed	The product needs to be tested	Manufacturing of package will be needed to start when order is arriving		
Distri-bution	Package needs to be transported to production site if out-sourced	If produced in-house, internal logistics become important	There could be a need of storing packages	The package will need assembly even if out-sourced		

6.4 Target Specification

Targets for the development of the package and the units they are measured in is presented in table 9. The targets uses data gathered in the design criteria list and interpreted needs of the customers.

Table 9: Specified targets and units the targets they should be measured in.

Target Specification	Unit
Package needs to be safe for users	$-$
Package needs to be safe for the environment	$-$
Package is modifiable in two dimensional horizontal direction	Yes/No
Package is modifiable in vertical direction	Yes/No
Package needs to follow international standards and legislation	$-$
Package needs to bear the weight of pumps inside	N, Pa, σ_y
Package needs to have 50-55 mm vertical clearance for lifting access for truck	m
Package needs to handle loads and strains during transport	N, Pa, σ_y
Package needs to follow international standards regarding loading packages into storage during transport	m
Package needs to use certified materials	Yes/No
Package needs to have fixturing support that fixates pump	m, N
Package needs to be easy to assemble and support stability at the packaging station	s, L_s
Package needs to have and follow international standards regarding lifting points, contents and other aspects	Yes/No
Package should strive to be stackable during transport	$pcs/transport$
Package needs to minimize its environmental impact	$Recyclability$ $Waste, Lifetime$
Pallet needs to weigh less than 20 kg	kg

6.5 Technical Principles

The technical principles are presented in table 10, and make use of previous development of the target specifications. The highlighted principles in the table are principles that are not going to be used. Lift with jack will be cumbersome and create safety issues, easy to slide and roll will also create safety issues even if safety measures where taken. Design automation is a interesting area, but the cost of hiring a professional to do it is at this time too high. Automate manufacturing is as well as design automation an interesting area, but has a too high start up cost.

Table 10: Shows the highlighted technical principles that should be removed from the project.

Main function	Technical principles		
Bear the weight	Palletize product	Custom pallets	Material choice
	Build support structure on pallet	Use ISO-pallets for different use	
Guard from environment	Custom sides	Pallet collars	HPE-standard sides
	Pallet rack	Place plastic around pump	Guard from corrosion
Easy to move	Easy for truck to operate	Lifting by straps	<mark>Lift with jack</mark>
	Lift by crane	<mark>Easy to slide</mark>	<mark>Easy to roll</mark>
Easy to assemble	By nails	Pre-determined connection points	Pre-made connectors for assembly
	Use screws for assembly	Use mechanical connectors	
Safe during use	Distribution of weight is centered	Fixate in CTU by:	Straps
			Lashing
	Correct labeling following global standards		Fill out material
Fit different sized pumps	Variable design	<mark>Design automation</mark>	Different solutions for each pump
Manufacturing of package	In-house	Out-source	Build some parts in-house and out-source other
	Built by operators	<mark>Automated manufacturing</mark>	
Distribution of package	Store pre-built packages	MTO packages which arrives at delivery station	MTO packages which arrives at kitting to be assembled on
	Produce pallets when pump is arriving to delivery		
Distribution of weight	Boards that distribute weight	Fixturing device that distribute weight	Beams under package that distribute weight in CTU

6.6 Group Technology

The visual inspection of the pumps show similarities in how they are constructed and by design. The differences that are noted during ocular inspection:

- **Size:** There are obvious differences in size between the different pumps.

- **Weight:** Influenced by size, but the weight is another obvious difference.

- **Handling:** How to handle the pumps, and ease of moving the pumps differ. Heavier pumps have to been move with different tools and the operator has to be more careful.

- **Building package:** How the package is constructed differs, where the smaller pumps can be placed on an EPAL 1 pallet with pallet racks, and the bigger needs a custom made pallet.

This is treated as a foundation for further analysis, which is to use specific data regarding the pumps difference in size. Presented in figure 23 and figure 24 where the difference of the pumps are shown by their frame size, and how much the assembled pump differ from a VASA and VASA HD pump in frame size 50. The size difference fraction is calculated to show eventual similarities in length and width between different pump-models in different frames, and how the pumps can be categorized respective their length and width.

SIZE DIFFERENCE FRACTION IN LENGTH

	25	50	80	100	150	200	250	350
Vasa	-15%	0%	45%	44%	63%	107%	143%	
VASA HD		0%	66%	91%	125%		143%	306%
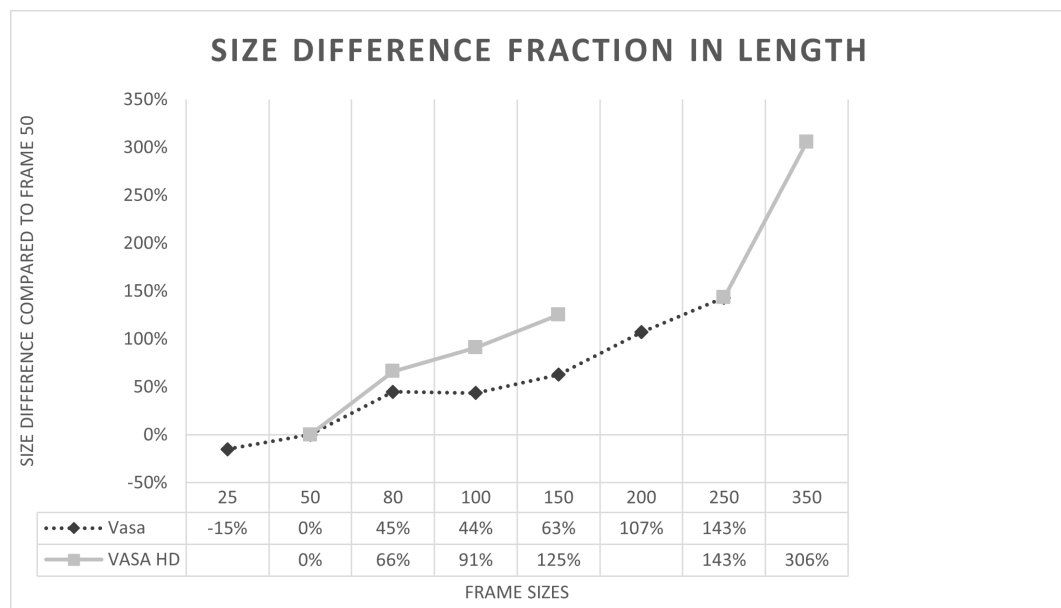
FRAME SIZES

Figure 23: Percentage difference in length compared with VASA and VASA HD pumps in frame size 50.
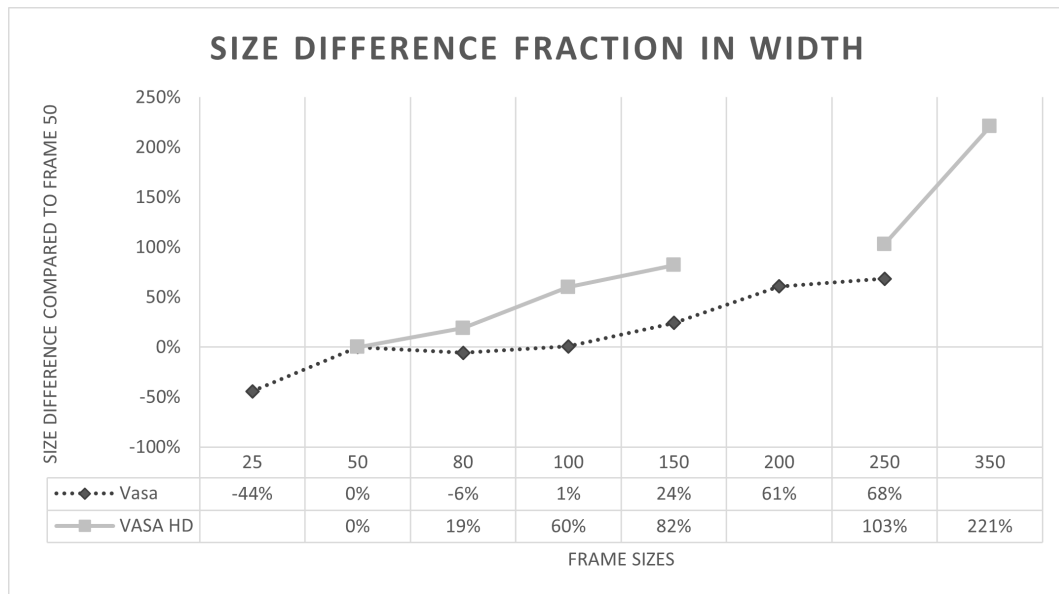
Figure 24: Percentage difference in width compared with VASA and VASA HD pumps in frame size 50.

These figures assist creation of part families with similarities, and by analyzing the different widths and lengths of the pump they can be grouped. Furthermore, analyzing the different pumps and if it would be possible to stack the pumps shows which pumps has the potential to being stacked. How the VASA and VASA HD pumps has potential for being stacked can be seen in figure 25. If the pump height exceeds 1,080 mm it has no possibility to be stacked, calculated with the height of an EPAL1-pallet. It has however possibility to be stacked if the height is below 1,080 mm in a 40 foot dry container.
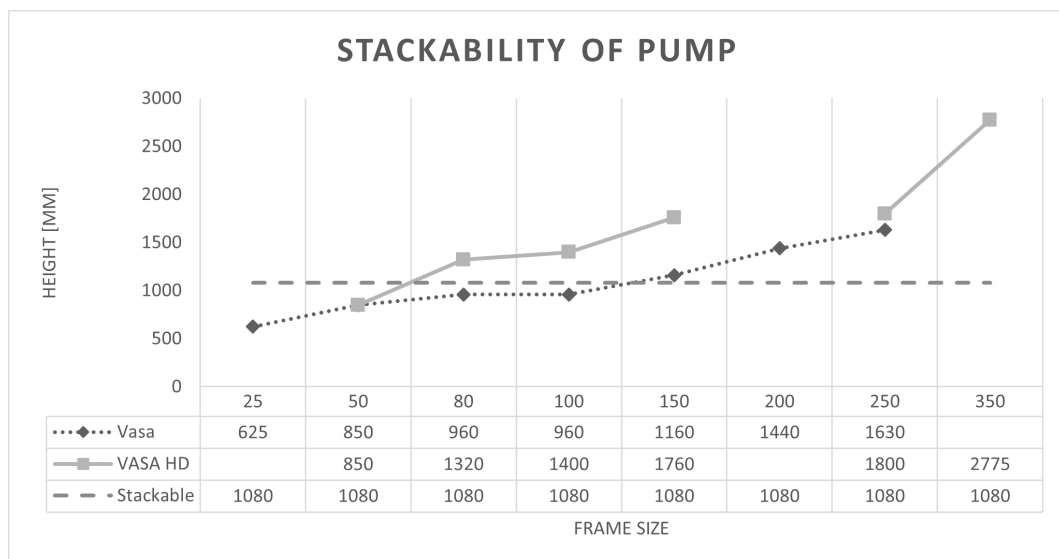
Figure 25: If a pump is below the dotted line, it has potential to be stacked in a 40 foot dry container.

7 Concept

This chapter explains how the developed concept is designed, its components and overall performance. Figure 26 is an overview of the concept with a pump assembled into the package. By reading further you will gain an insight in how the package is designed.
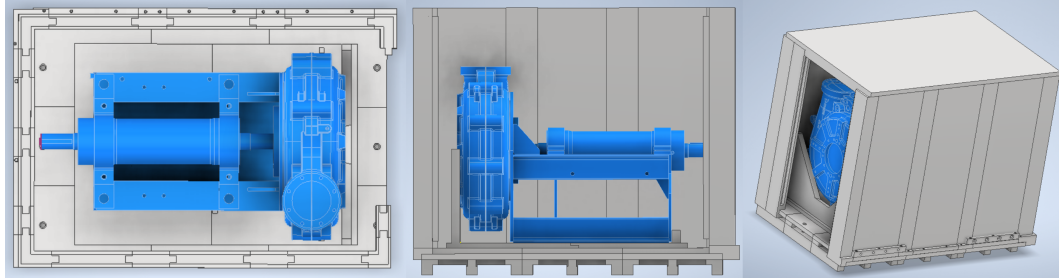
Figure 26: Final concept of package solution. For visibility are the sides hidden.

The package concept is a modular solution, where different parts are built together into different sizes. It is modular in two dimensions, length and width, to suit the big variation of sizes of the pumps at Metso. All the parts are standardized and can be built into different configurations without added support. The size of a 2x2 pallet module build is the size of an EPAL1-pallet. This concept can be seen as a product portfolio where the customer can pick and choose depending on needs. The different modules are listed below and explained further in coming chapters.

1. Pallet module

2. Side modules

3. Side connector modules

4. Corner modules

5. Fixturing module

6. Fastening module

7. Roof

7.1 Pallet

During development it is determined that the pallet is a crucial part for the performance of the concept. The pallet is the main load bearer and distributes the weight, and at the same time handles the forces applied on the package during transport. It is also the main driver for size of the package, except for the cargo it holds. So, development of the pallet is crucial to fulfill the targets and requirements. Furthermore, the variation of pump size and weight combined with production cost for the pallet is pointing in the direction of modularization.

This pallet uses modularization and standardized pallet sizes by the ISO-6780 standard to reach a pallet customizable in width and length, but still fulfilling

standard sizes for pallets. This module has a loading area of 600x400 mm, which is half the length and half the width of an EPAL1-pallet, see chapter 3.5. This means that if four modules are built together, it will match the loading area of one EPAL1-pallet, 1,200x800 mm. Furthermore, if the cargo only needs a fourth of the size of an EPAL1-pallet it is possible with this concept to utilize space by using a smaller pallet for that application. The pallet is developed to fit into each other for fastening, secured with a wedge or bolt in the predefined holes. The design offers multiple ways to pack the cargo, in a box, with a hedge or without sides, see next chapter 7.2.
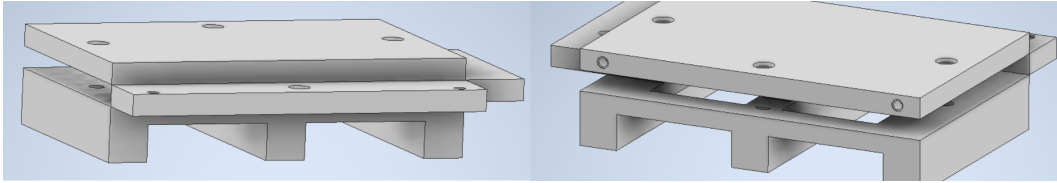
Figure 27: Pallet module for the pallet.

The holes in the pallet are for ease of assembly, where a bolt or a wedge can be used to support the connection of the modules in a horizontal direction. It is designed to suit heavy pumps, which creates friction between the modules, and thus horizontal stability.

The pallet follows the necessary clearance which is needed for lifting with a truck, which is 50-55 mm clearance for the forks. During lifting, the pallet make use of the support structure, see section 7.3, and the fact that the pump will be secured to the assembled pallet. This will spread the forces of the lifting action.

The pallet module is built together by different beams and joining methods. The proposed assembly method is to use nails if it is a wooden pallet, and similar joining method if any other material is used.

7.2 Side Modules and Side Connector Modules

Side modules are designed to not constrain the size of the pallet because of the size of the sides. It is designed to be standardized parts which all can be built into different configurations, not depending on the amount of base pallet modules used. To achieve this the modules have been split into three categories, *module overlapping sides*, *corner modules* and *filling side*. These three different categories consists of a total of twelve modules. The sides have predetermined holes for assembly into the pallet for stability, these holes are used for fastening bolts into the pallet. Table 11 shows amount of modules per group of modules.

Table 11: Number of modules in each category of sides.

Category	Type of modules
Module overlapping sides	4
Corner modules	4
Filling sides	4

However, there are similarities between the modules as they should be placed next to each other and be able to be joined. The joining is split into three different areas for all side modules. Bolt holes or holes for wedges, where the sides are being fixated onto the pallet by pre-determined holes. Next are the channels and overlapping sides which fits into each other, thus helping the modules to fit onto the pallet. The third joining method used is the channel for the roof, where the roof will add stability to the sides, and is explained in chapter 7.2.4.

The height of the sides needs configuration for each package built and this is because of the different configurations of pumps vary very much in height. It is not only the pumps that varies in height, the motor and its drive is the two things that are adding height to the pump. What motor is used on the pumps have big differences between the orders, as there are no standard motors used. This causes the variation to be too much for modularized design without compromising the structural integrity of the sides.

7.2.1 Module Overlapping Sides

These modules ensures that the sides of the package stays modular and do not depend on the pallet width or length. This category consists of four different modules, each suiting a different place on the pallet module. It is necessary to have different modules due to the design of the pallet module's sides. These modules are, at the two sides where there are space between the plates at the pallet module, filling out this space and giving support to the overall structure when loaded.
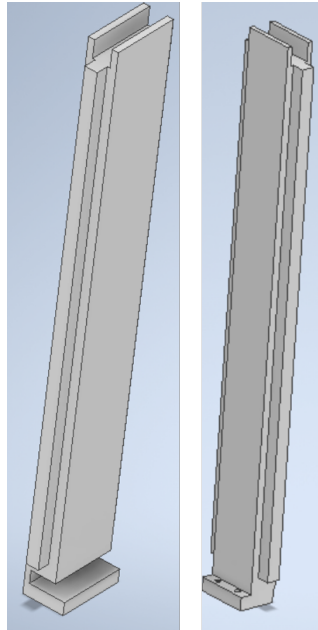
Figure 28: Visualization of the module overlapping sides.

7.2.2 Filling Sides

These modules have four different designs, for each side of the package. It has a standardized length to fill out the space between the corners and module overlapping sides. It fills the same function as the module overlapping sides. Filling sides needs to exist to not have side module lengths depending on the amount of pallet modules used.
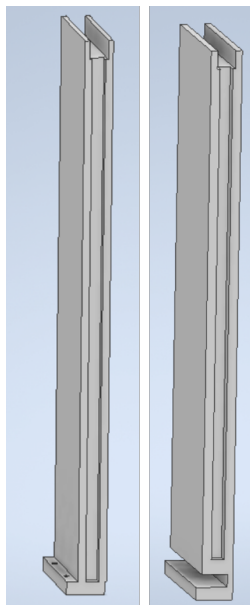
Figure 29: Filling side modules that fill out space at the sides.

7.2.3 Corner Modules

The corner category is also split into four different modules for the same reasons as the module overlapping sides. Each corner of a pallet module is different, thus needing different designs of the corners. The amount of corner modules needed will always be four, independent on the amount of pallet modules. So if the package needs a box, there will always be four corner modules. This makes it possible to produce in larger batches due to it always being the same amount of modules for every package.
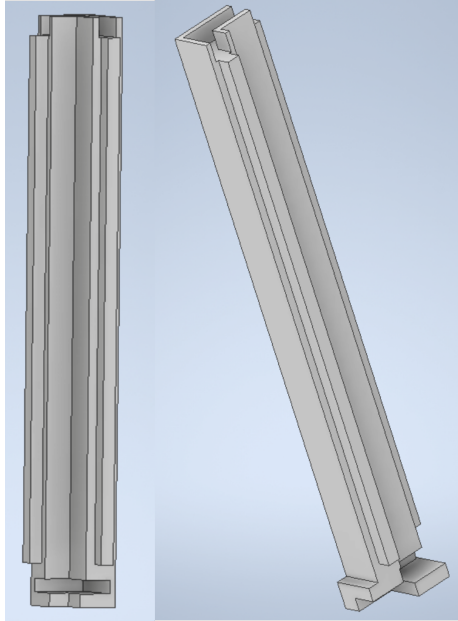
Figure 30: The corner modules for the different corners and the differences in connections to the pallet.

The two corner modules shown in figure 30 show two of the corners and the adaptation needed for the connection to the pallets.

7.2.4 Roof

The roof is custom made for the size of the pallet due to it being a supporting mechanism for the sides. The added beam at the corner adds structural integrity to the sides, and is assembled in the channels of the sides. The roof is fastened onto the sides, and should not need any more support as no forces will be applied on the roof in a vertical direction. However, there is a possibility to fasten the roof with a screw or similar joining method to the sides, adding security. It is determined that stacking is not possible due to the increased demands of the sides will create a structure which adds to much complexity or weight to the sides.

When lifting a pallet with straps, it is important that the roof does not go the entire width and length of the sides, as this would cause stress on the roof and further the sides of the pallet. The roof is designed to have 5 centimeters of room between the edge of the side and the edge of the roof, leaving necessary space for the straps.
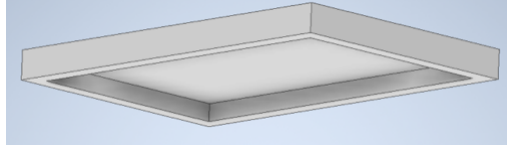
Figure 31: Roof of the package, which is assembled into the top of the sides and corners.

7.2.5 Fastening

External fastening during transport is only needed when it is sent as a package, and not only a pump on the pallet. This is due to the pump having points for fastening, which is used if no sides or roof is used. But if a complete package is used, there is a need for fastening points on the pallet. This is solved with four different modules attached on the sides, and fastened in the pallet modules. In these modules is the fastening aids are mounted to make the package safe during transport.
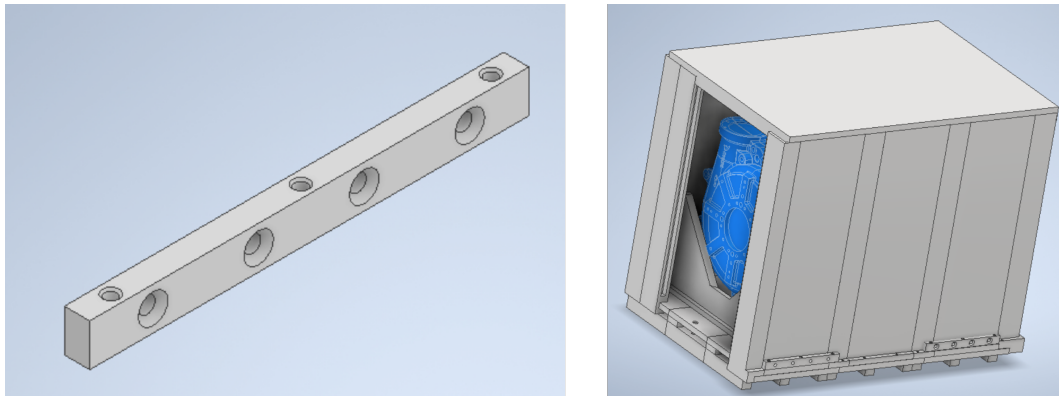
Figure 32: Securing module for the pallet. It is mounted to the pallet with the small holes, and the fastening aids mounted in the big holes, going through the side into the pallet for support.

7.3 Support Structure

The support structure is developed to suit different types of pumps, and exists in five different versions. Every version can hold multiple pumps and is suited to the different bolt hole placement on the different frames, thus reducing variants of the support structure. As seen in figure 33, the design is, rather than act as a load bearer, designed to work as a safety mechanism for tilting. It is also designed to support the base pallet modules when lifted, to balance the loads. And distribute the force of the pump over larger area of the assembled pallet.
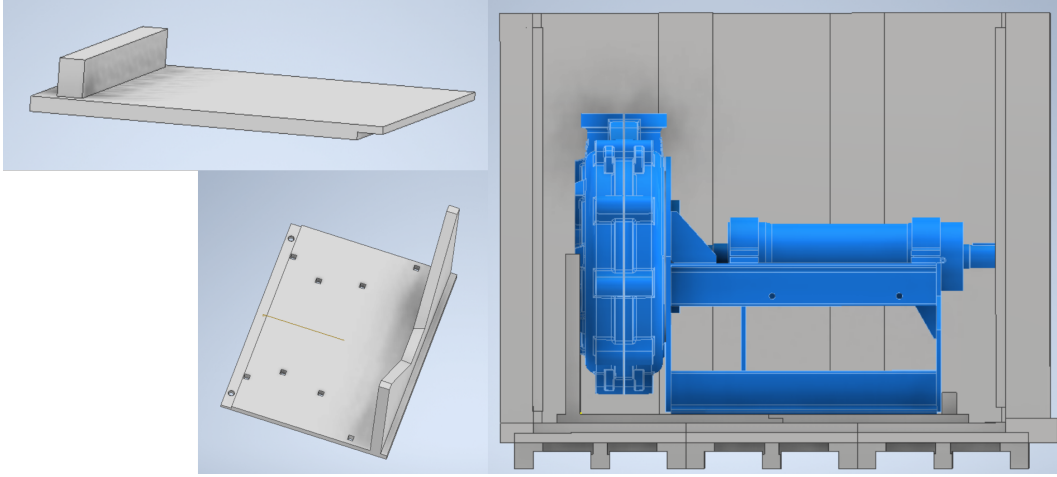
Figure 33: Support structure for the pump on the pallet. The rectangular holes matches the holes for bolts on each frame the different sizes of support structure suits.

7.4 Evaluation of Design

The evaluation of design needs to verify that the loads on the pallet can be endured during transport. However, the calculations are simplified. For this calculation, the heaviest pump is used. Because if the pallet can bear the weight of the heaviest pump, it can bear the weight of the less heavy pumps.

Calculating the maximum stress in the pallet gives an indication about the durability of the design.

$$\sigma_{max} = \frac{FL}{CZ}; C = 16, Z = \frac{wh^2}{6} \tag{8}$$

$$F = mg = 9440 \cdot 9.82 = 92.7kN \tag{9}$$

$$\sigma_{max} = 42.5MPa \tag{10}$$

It is however not realistically that all of the force will be concentrated on one base pallet module. The support structure will distribute the force over the pallets. If the pallet module need to bear half of the weight of the pump it will lead to a maximal stress of:

$$\sigma_{max} = 21.3MPa \tag{11}$$

If the pallet module need to bear a third of the weight it leads to a maximal stress of:

$$\sigma_{max} = 14.2MPa \tag{12}$$

However, for the pump this size and weight the amount of pallet modules needed are 30 modules, see chapter 6.6, thus making it unrealistic to have the load spread out on two or three modules. Furthermore, it is also unrealistic to have the load spread evenly over the assembled modules. An estimation is done to calculate the load on a fifth of the modules needed. This is because the footprint of the pump connected to the pallet is by its frame, and even though it is mounted on the support spreading the load. It will have higher forces applied where the frame connects to

the support structure. In this the forces applied on the package during shipping is included, where $0.2 \cdot g \Rightarrow 1.8 \cdot g$ in a vertical acceleration will affect the package, see chapter 3.4.

$$\frac{\sigma_{max} \cdot 1.8}{5} = 15.3 MPa \tag{13}$$

Leading to yield strength must be above 8.5 MPa. This is possible because of the width, w, in equation 8 is five time the size and no other changes are made in the equation. Leading to $5 \cdot w \Rightarrow \frac{\sigma_{max}}{5}$.

$$\sigma_y \geq \sigma_{max} = 15.3 MPa \tag{14}$$

One base pallet module has a volume of 0,0217 cubic meters, and the aim is the have one module weighing less or equal 20 kg.

$$m \leq \rho \cdot V \Leftrightarrow \rho \geq \frac{m}{V} = \frac{20}{0.0217} = 921.159 kg/m^3 \tag{15}$$

A stress analysis is made to identify eventual weak spots of the design. This simulation is conducted in the program Autodesk Inventor and uses the heaviest pump, which weight is 9,440 tonnes, and applying that pressure on the support structure. The support structure moves the load onto the pallets and the results is shown in figure 34. The weight which correlates to the pressure applied is 5.6 times more compared to a pump which should be mounted on that many pallet modules. Figure 34 shows that maximum von Mises stress is 2.56 MPa, which shows great margin compared to calculated value in equation 14.
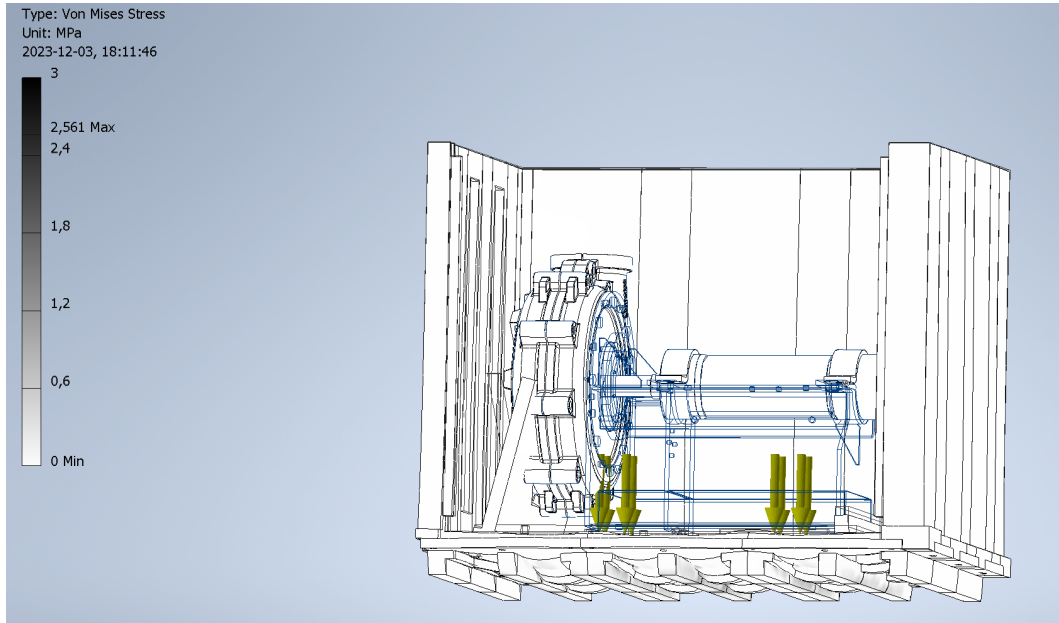
Figure 34: Stress analysis of the package, when loaded with 0.39 MPa at each of the support structures parts. For visual purposes have the deformation been exaggerated.

7.5 Material Choice

This section covers the results from the material choice for the package modules.

7.5.1 Material Choice for Pallet Module

Using a material database, Ansys Granta Edupack, it is possible to get an overview of materials that would be possible for use in certain products. The materials have been sorted if it fulfills required a yield strength, cost, density and if it is a renewable resource and its carbon dioxide footprint during primary production. The constraints set to filter out material are:

- Yield strength: $\sigma_y \geq 15.3 MPa$

- Density: $m \leq 20kg \Rightarrow \rho \leq 921.2kg/m^3$

- Non-conductive materials

- Acceptable, good or very good use in wet conditions

- Cost of producing one kilogram of a specific material

- Carbon dioxide emissions per kilogram produced material in primary production

- If it is a renewable resource

Where the yield strength and density only is affecting the material choice of the pallet. Material choice for the other modules is presented later in this chapter, see section 7.5.2.
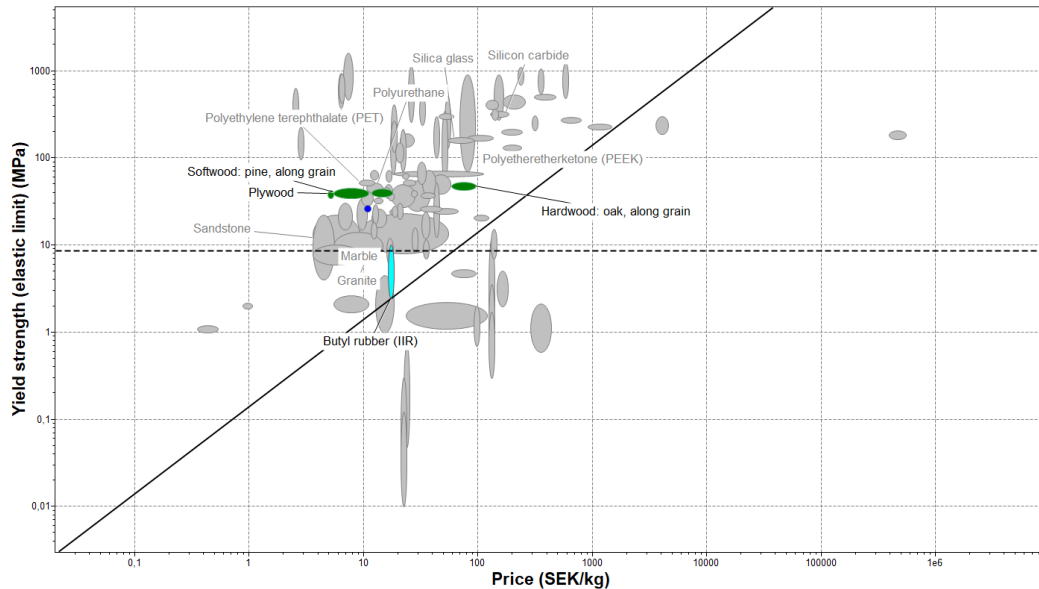
Figure 35: Material choice process with filtering out material due to density and yield strength. X-axis shows cost per kilogram produced for the different materials. The coloured circles are the ones fulfilling the requirements.
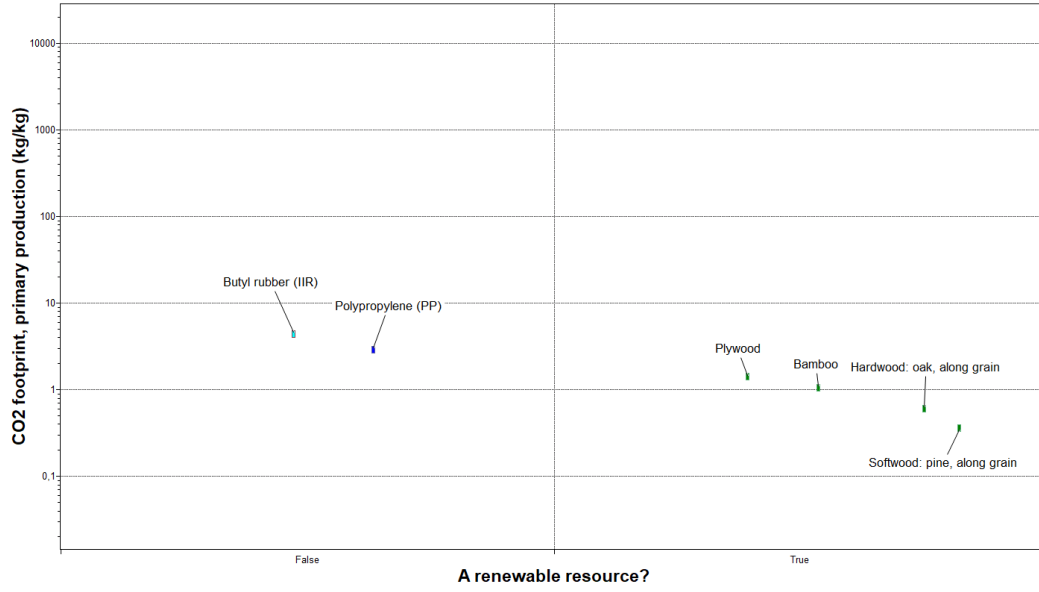
Figure 36: Material choice process continuation, where the materials are grouped depending on if it is renewable or not. Y-axis shows emitted carbon dioxide per kilogram produced material in primary production.

From this filtering, there are five different materials presented in Granta EduPack that are possible to be used for this project and fulfilling all targets. Rubber material is removed even though it is passing the filter process, its properties does not suit the pallet module. The four materials left are specified in table 12.

Table 12: Material alternatives fulfilling the targets.

Material	Density $[kg/m^3]$	Yield strength $[MPa]$	Price $[SEK/kg]$	CO2 emissions $[kg/kg]$	Renewable
Bamboo	602-797	35.8-44	11.9-17.8	1.00-1.11	Yes
Oak	850-1030	43.2-52.8	59.3-95.2	0.57-0.63	Yes
Pine	440-600	35-45	5.49-11	0.35-0.38	Yes
Plywood	700-800	34.4-42.1	4.87-5.4	1.35-1.48	Yes
Poly-propylene	895-909	24.1-28.4	10.2-11.4	2.77-3.06	No

A safety factor is needed which is double the needed yield strength, ruling out polypropylene as an option. Comparing this to the stress analysis in figure 34, the yield strength are significantly larger compared to the simulated von Mises stress.

$$\sigma_y \geq S \cdot \sigma_{max} = 30.6 MPa; S = 2 \qquad (16)$$

Materials that fulfill the requirements are different kind of wood and bamboo. Material that looks promising are pine, plywood and bamboo due to their price, emissions and yield strength. Oak is too expensive to use, and can even be too heavy to use.

However, to manufacture the modules it needs to be possible to easily process the materials. This information is taken from Ansys Granta Edupack empirical data about processability, which is shown in table 13 and is ranked on a scale from 1-5 where 5 is highest processability.

Table 13: Processability for different materials.

Material	Moldability	Machineability
Bamboo	1	4
Pine	2	5
Plywood	3	5

The different materials in table 13 shows different machineability abilities, and this is important in the project as manufacturing of the modules strives for lowest cost. As for building the pallet module, it can be built by using wooden planks or beams and joining them together.

7.5.2 Material Choice for other Modules

As the pallet and support structure are the only two modules that bear the weight, the other modules does not need the same durability. There are requirements for some of the sides, the sides are connected into the pallet which should bear weight, but are enclosed by the pallet. The different modules have different requirement on processability as their geometries are different. Moldability is more important than durability for the sides and corners as they have more complex geometry. Given that the possibilities are there to use fully recycled plastic for the sides, corners and roof. It will help protecting the cargo from the environment, such as water and wind.

For the support structure the durability demands are high as well, but not as high as the pallet module. The support structure may need reinforcements for the heavier pumps, but for the middle sized and smaller pumps a fully recycled plastic or wooden structure is proposed.

7.6 Evaluation of concept

Evaluating the concept and how it is fulfilling the targets is done in table 14. It fulfills most of the targets, and the targets it does not fulfill has explanation of why it is not fulfilled.

Table 14: Target specification,

Target Specification	Unit	
Package needs to be safe for users	$-$	Yes
Package needs to be safe for the environment	$-$	Yes
Package is modifiable in two dimensional horizontal direction	Yes/No	Yes
Package is modifiable in vertical direction	Yes/No	No
Package needs to follow international standards and legislation	Yes/No	Yes
Package needs to bear the weight of pumps inside	$N, Pa, \sigma_y,$ σ_{ts}	Yes
Package needs to have 50-55 mm vertical clearance for lifting access for truck	m	Yes
Package needs to handle loads and strains during transport	$N, Pa,$ $\sigma_y, \sigma_{ts}, \sigma_f$	-
Package needs to follow international standards regarding loading packages into storage during transport	m	Yes
Package needs to used certified materials	$-$	
Package needs to have fixturing support that fixates pump	m, N	Yes
Package needs to be easy to assemble and support stability at the packaging station	s, L_s	Yes
Package needs to have and follow international standards regarding lifting points, contents and other aspects	$-$	Yes
Package should strive to be stackable during transport	pcs/CTU	No
Package needs to minimize its environmental impact	EOL $Waste,$ $Lifetime$	Yes
Pallets weight needs to be less than 20 kg	kg	Yes

The height of the pumps vary, not only because of the products Metso produces, but on what motors that should be used for different applications. This leads to a high degree of uncertainty of the needed height of the sides, and a very high variation. At the same time the side's height is easy to change between orders as it is not complex design to change the height.

The stackability of the developed concept has not been verified. Clear limitations exists as the force would move down through the roof, via the sides and onto the connecting sides on the pallet. Where those sides on the pallet lacks support from the ground, making it weaker to a force applied in vertical direction.

8 Estimated Effect and Implementation in Production

This chapter covers the different effects this will have on the production, but also how the concept should be implemented. Specifying changes needed for an effective implementation of the concept into production.

8.1 Group Technology

Group technology is categorizing the different pumps into groups, and the categories indicates amount of base pallet modules needed for each of the VASA-pumps. The table below is presenting one way to group the pumps, where it would be categorized by a serial number. The serial number is shows group (g), number of base pallet modules in width and length($n.o.wxl$), if it needs sides(s), pump (p) and frame size (f), looking like this $g-n.o.wxl(s)-p-f$. This serial number would be for a VASA 234-pump needing sides, 2-321s-V234-80. It would be for a VASA HD 364 without sides, 4-623-HD364-80, i.e group 3, 6 modules; 2 in width and 3 in length, pump and frame type. This will help with categorizing the pumps and to know what is needed to build the package. This serial number can also include more information, or be included in existing serial numbers. The serial numbers are developed to help ordering the package modules, as the serial numbers will tell people planning operations how many modules are needed for specific pump orders.

Table 15: Grouped pumps relative to their need of modules.

Group	Number of modules (WxL)	Pumps		Frame
1	1 (1x1)	VASA	161	25
			234	50
2	3 (1x2)	VASA	302	50
		VASA HD	302	
3	4 (2x2)	VASA	214	80
			213	
			214	
			253	
			254	
			284	100
			285	
			303	
			332W	
			334	
			335	
4	6 (2x3)	VASA	336	150
		VASA HD	364	80
5	9 (3x3)	VASA	459	200
			509	
			488W	
		VASA HD	455	100
			507	150
6	12 (3x4)	VASA	5311	250
			5311W	
		VASA HD	5311	
			5311W	
7	30 (5x6)	VASA HD	8515	350
			9015	

8.2 Safety

Safety was an area of interest identified during the analysis of the current state. Where different aspects considered to be a risk for operators or causing damage to the pumps. The main concern was the risk while tilting the pallet, where the support structure for the pump makes a big difference. This structure will force the operators to fasten the pump into the pallet, and adds more security by the frame in front of the pump. It also ensures that no pump houses are placed hanging out over the pallets, thus reducing risk of falling over when tilted slightly.

Another aspect to consider is during pump assembly, it has however been outside of the scope but it is nonetheless adding safety during assembly of the pump, but more analysis needs to be done to find out what is needed from the pallet in assembly.

Standardizing the pallets used in shipping will ensure a consistent performance of the pallets. This when trying to find ways to improve, or finding faults in current setup. If there are one package used, and it has problems, it will be easier to search for problem in that or in the process building it compared to custom make package for each pump. This solution needs to be verified, but when done it gives a certainty for the organizations using the pallet that it will perform to certain standards.

8.3   Concept in Production

The production will be improved when introducing the presented concept for packaging. The different parts will however demand changes in flow of products and parts through the factory. Expected results estimates a time reduction connected to building package and packing pump of 70-80 percent per pump packed. Time reduction and estimation on production is presented further later in this chapter.

As most products, the design and functions determine in which order the product must be assembled. This is applied to the package as well, where the first to assemble is the base pallet modules, and the order of assembly is noted below:

1. Base pallet module

2. Support structure for pump

3. Sides

4. Corners

5. Roof

6. Fastening modules

The order of operations is needed to be according to this, except for the assembly of the roof and fastening modules where the order does not matter. The order of assembly is proposed as such due to where in production the different parts should be used. It is proposed to use the base pallet module and support structure as a pallet where assembly of the pump can be performed. This is done to reduce wasteful operations, such as move the pump from one pallet to another at the packing station.

There are differences in how the pump needs to be packed depending on how it should be shipped. Not all shipments needs package with sides and roof, but only a pallet with the pump fastened to it. This has big implications on material and information flow of the package.

8.4 New Operations and Line Balancing

Introducing a new way of packing the pumps leads to new ways to operate the packaging process. The different operations is specified in table 16. All the times are estimated but information has been gathered from experience of the operators. The operations differ depending on where the assembly of the base pallet modules are being assembled, but overall structure is the same.

Differences to current setup is where the operations are being done. Assemble or handling the pallet is done at the kitting station. This enables assembly of the pump on the pallet, removing the wasteful operation of changing pallet between the assembly of pump and packaging station later in the process. It also standardize what pallets and support structures that are being used in assembly. However, a study about how the support structure perform during assembly needs to be conducted.

Table 16: Revised line balancing. What operations exists with the new concept, their order and the estimated time for each operation. This table is done to match the size of pump in figures 16-18.

Operation	N.o. times performed	Number	Preceded by	Estimated time/op	Total time [min]
Kitting station					
Assemble base pallet module	6	1	-	0.75	4.5
Secure base pallet modules	6	2	1	0.3	1.8
Secure support structure onto pallet	1	3	2	2	2
Packaging station					
Put plastic on pump	2	4	Pump assembly	2.65	5.3
Assemble overlapping module sides	8	5	4	0.75	6
Assemble filling sides	12	6	5	0.75	9
Assemble corners	4	7	6	1	4
Assemble fastening	8	8	6	0.3	2,4
Assemble roof	1	9	7	3	3
Total time with assembly of pallet					**38**
Total time without assembly of pallet					**31.7**
Total time without sides					**13.6**

70

Total amount of time is compared to the study done, see figures 16-18, is 35,5 percentage or 29,6 percentage of total time consumption compared to current state. This leads to an efficiency increase of 282 percentage or 338 percentage, potential increasing output to more than 3 times of today. If the package does not need sides, it is a 22 percentage lower than the time it takes to build and assemble the pump onto the pallet with current setup. It gives the potential for 4,5 times the amount of output of pumps delivered without sides and roof.

8.5   Internal Logistics

Internal logistics is important determining the flow of material, parts, products and information. This is affected by the functions of the products, and as the concept is developed to support the production and primarily the packaging of the products the functions are clearly defined.

Suggested approach for the kitting station is visualized in figure 37. It is a sequenced part flow to the kitting station, where orders for the pump correlates to the parts received at the kitting station. The kitting station then gather all the necessary parts and structure it for the assembly of the pump. Regarding the pallet and support structure, there is two different approaches. Assembly at the station or receive the assembled pallet from another company. Either way, the delivery of base pallet modules and support structure match the pump assembly orders. The pacing is suggested to be a synchronous transport, where a buffer time exists to not introduce stress to the operators. This pacing gives control over time management and planning, knowing time consumption at the different stages. As the operations are simple, and buffer time exists no stress will be introduced at the stations. During an implementation phase, the pacing can be asynchronous to give the operators time to get familiar with the operations,
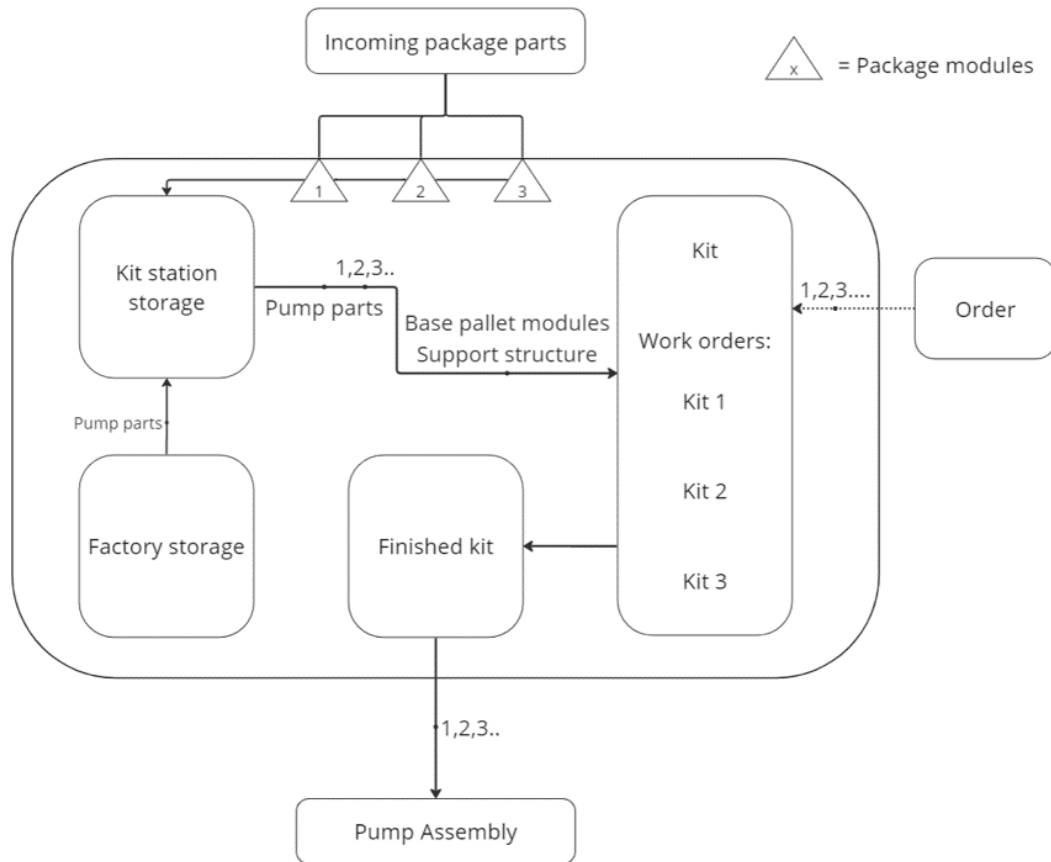
Figure 37: Flow of parts for assembly of the pallet and support structure at the kitting station.

Suggested approach for the packing station is visualized in figure 38. It is a sequenced product flow to the two packing stations. The numbers are representing packages for one pump and the different parts, and is received at the packaging station with the pump assembled on the pallet and support structure. At this station the assembly of the sides, corners, roof and fastening modules is done and the parts are delivered to the station. The delivery are sequenced according to the flow of the pumps through the factory. If pump number one needs eight side modules, it will be delivered to station one just before arrival of pump number one.
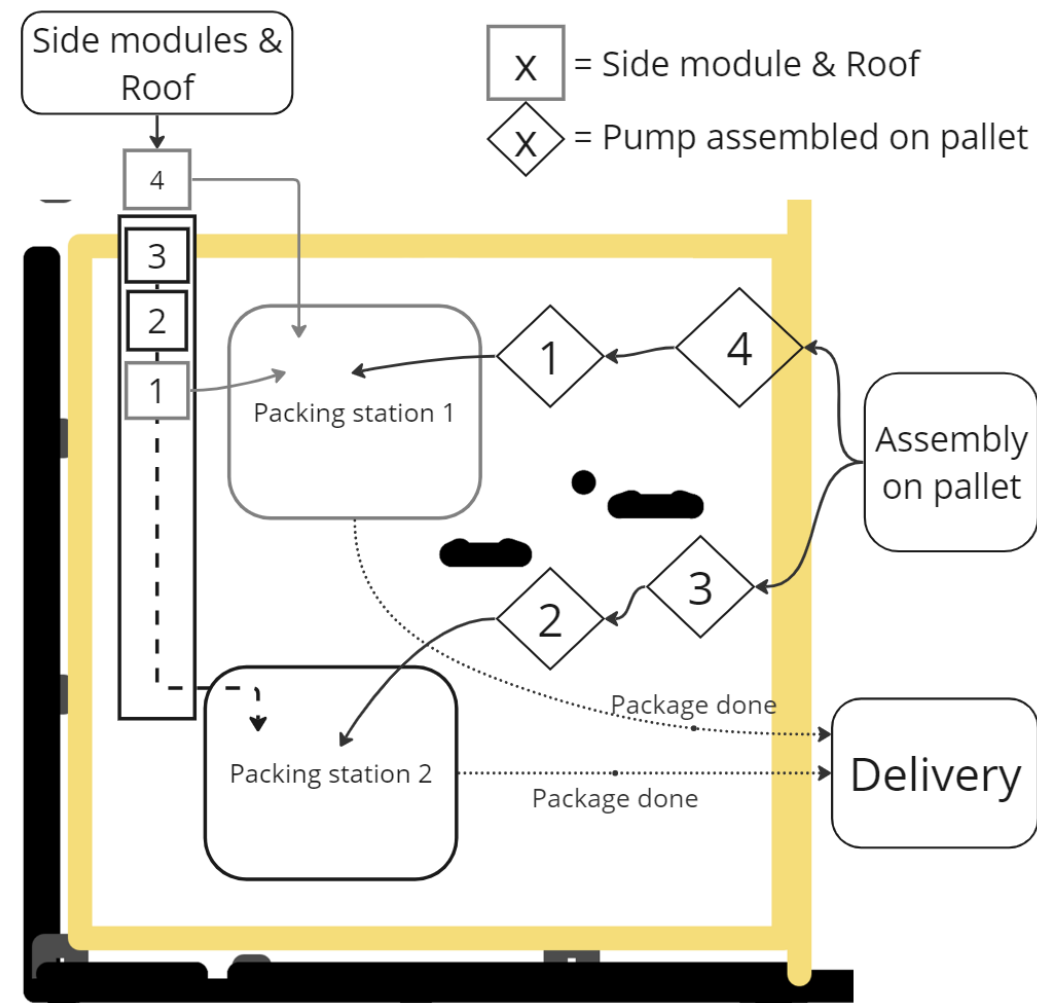
Figure 38: Flow of parts for assembly of the package at the packing station.

This way of internal logistics puts demands on the rest of the organization, and the flow of information. The planning of the production will need to be changed, but are explained in next chapter.

8.6 Revised Value Stream Mapping

The value stream mapping is greatly influenced by previous chapters as the flow of material and information needs to suit the new concept. There are two main areas that need to be considered when implementing this concept, material and information flow. These two have a big impact on the production, and the success of implementation. The revised value stream mapping is presented in figure 39, where the new flows are in the grey, line spaced boxes in the map. Compare with figure 20.
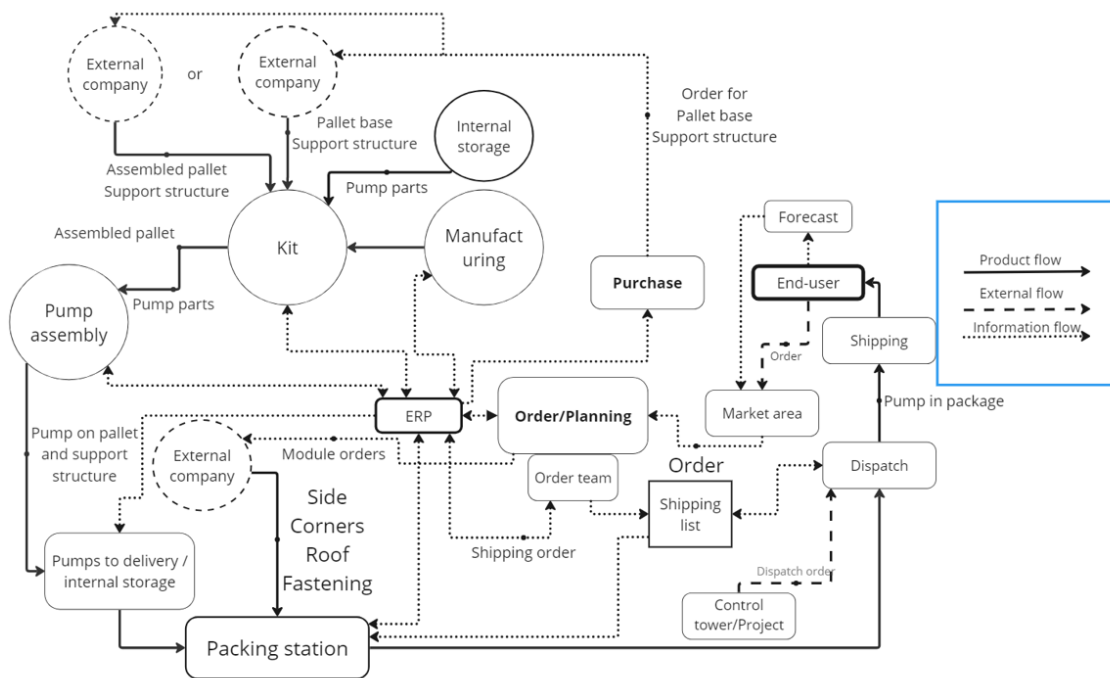
Figure 39: A revised value stream mapping for the implementation of the package concept in production.

Information flows are important in planning, execution and review of the process. The information flow that will be different compared to current setup is mainly affecting planning organization, packing station and kitting station. The information needed at each step is:

Table 17: New information flow that needs to exist for the concept to work.

From organization	To organization	Information
Planning	External	Amount of base pallets for the specific order
	External	Height of sides and roof size
	Kit	Amount of base pallet modules
	Packing station	Amount of modules for the specific order
	SAP-data	Register amount of modules for specific pumps
Kit	SAP-data	Finished assembly of pallet
Packing	SAP-data	Finished assembly of pallet
Existing information flows which will be used		
Assembly of pumps	SAP-data	Finished assembly of pump
Market area	Planning	Type of pump

This information is the foundation for implementing the concept. Planning needs to have an easy way to know amount of modules and can use serial numbers for the pumps, specifying amount of modules needed. Additional information that planning needs to have easy access to is the height of the assembled pump. This will determine height of the sides. Additional information needed for the order of package is the type of package, if it should have sides or not.

Operation	Explanation	Status
Transportation	Move pump	Modified
Operation 1	Build pallet	Removed
Operation 2	Build support structure	Removed
Operation 3	Move pump to pallet	Removed
Operation 5	Build sides	Removed
Operation 7	Build top	Removed

Table 18: Removed or modified operations in the packaging station compared to current state.

The table 18, is explaining what has been removed and what has been significantly changed compared to today. The building of the package is completely removed even though assembly of pallet is introduced, and moving the pump from one pallet to another is removed as well. However, there are some operations still in place. Such as putting plastic onto the pump. The plastic operation is the same as today, where it is an efficient way of working. The information flow has also changed.

The packaging station gets information early about what pumps that needs to be packed, and in which package configuration they should be. Thus knowing how to plan the workload between the two stations during a day, but also prepare which parts and materials that needs to be used during that day. Working in this manner, the packaging station is well prepared for spikes in demand, and can allocate resources accordingly. Figure 40 is showing the new flow of material and information through the packaging station. The information flow is set as push or pull, and it depends on how it is implemented. This solution will work as a push system, as the modules are delivered to the packaging station at the same time the pump is. But in a transition phase, where the packaging station needs a stock of modules there are more like a pull system. Where the operators at the packaging station notifies the planning organization when they need refilling.
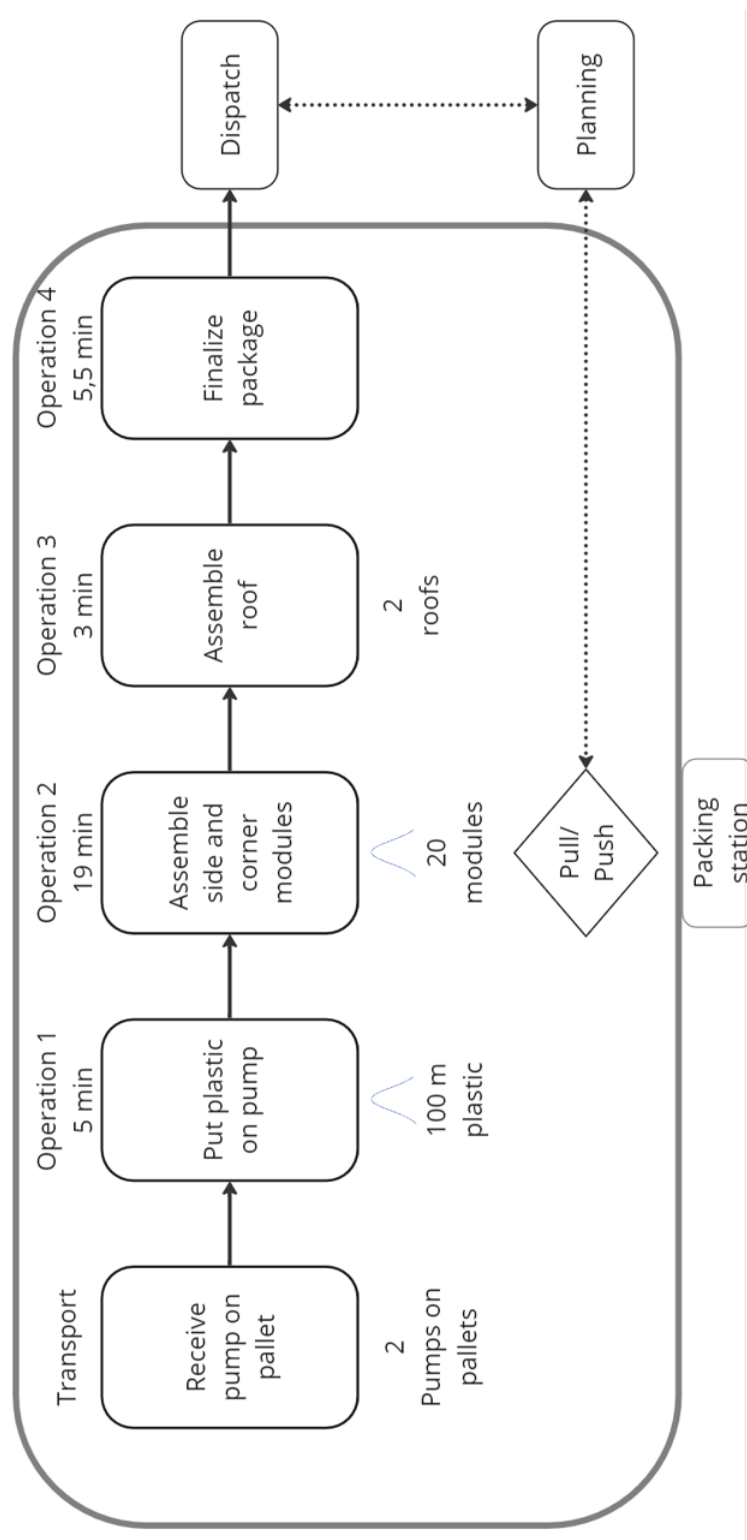
Figure 40: Revised value stream mapping of the packaging station.

8.6.1 General Improvements of Production

The proposed flow of material and information suits just-in-time production because of the sequential delivery of the modules timed with the pump. But it is possible to adapt it to be working in a couple of days intervals. Because of the information that exists about pump orders long time in before packed, it is possible to predict the demand of package module at the different stations. It is possible to do just-in-time production if the module for the package is delivered when needed at respective station. This will remove any need for storage of modules or wood, and free up space.

However, if just-in-time production is not possible due to limitations in the delivery chain of modules or other challenges. A similar approach can be taken, where the planning cycle is a couple of days. As the orders of the pump is coming in relatively long time before it should be packed, it is possible to predict the demand of modules at respective station. This leads to the possibility to have two flows of modules, one to the kitting station and one to the packing station. And as Metso know how many pumps that should be delivered during that time, they also know how many modules they should order for this cycle. This leads to reduced storage, as they only need to store modules for a couple of days, or other specified time frame suiting the storage and delivery of module possibilities.

9 Results

This chapter will cover the most important aspects of the results and visualize performance indicators. An overview of the concept will be presented, and certain aspects of the production analysis.

9.1 Information Needed to Develop a Package for Global Shipping

There are a lot of different standards, legislation and guidelines regarding global shipping. Countries are applying different standards and legislation, where some countries are stricter. Analyzing standards used in global shipping today gives an understanding about what information is relevant for the project, and also about the market. Where does the focus lie? In shipping there are a few different areas which is being covered in many standards, legislation and guidelines. And they are sustainability, safety and pest control.

Standards, legislation and guidelines which are useful when developing a package are presented in table 19. Regarding transportation by road, there are different regulations and standards for almost every country. Where some organizations, such as European Union, have some standards regarding their roads. But when developing a package, the receiving countries regulations should be considered.

Table 19: Standards, regulations and legislation which should be considered when developing a package for global shipping

ISPM-15	Use of wood in packages, and the necessary treatment the wood needs to have in order to be used
ISO 6780	Standard pallets sizes used globally.
HPE packaging	Guidelines which are presenting a minimum standard for reliable packaging for shipping technical equipment
CSS-code	Transporting cargo by sea, and what to consider during the transportation
CTU-code	Code of practice for packaging cargo units. Gives understanding about the demands on the packages during transportation, such as securing the package.
GDV packaging handbook	Handbook which aims to reduce loss of cargo during transportation
SOLAS interventions	Safety at life of sea is the full name, and here information about handling of cargo regarding safety can be found. IMO is developing global regulations regarding transportation by sea.
IATA standards and regulations	IATA develops and maintains standards and regulations about transportation by air.

9.2 Summary of concept

The developed concept is a modular package which is based on pallet modules a fourth of the size of an EPAL1-pallet. The pallet modules together with the height of the sides is what determines the volume of the package. Amount of pallet modules is determined by the size of the product, or cargo, that should be transported. The smallest amount of pallet modules that can be used is one. There is no limitation to how many modules that can be assembled, but testing needs to be conducted to ensure durability when building many pallet modules together. The sides consists of different modules, two different on each of the pallets sides and four corner modules. This ensures that the size of the sides does not matter, only how many of them.
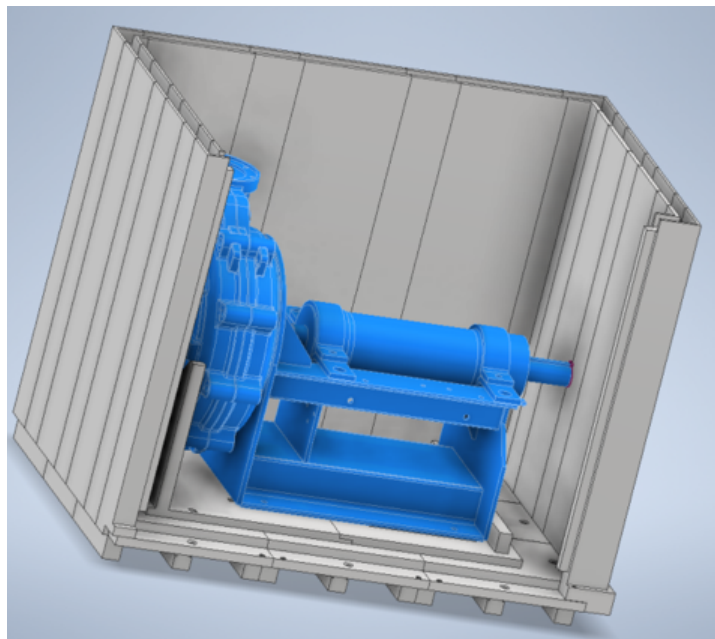
Figure 41: Pump mounted in the package.

The pump is mounted on a support structure, which helps with distributing loads onto the pallet modules. It also has a beam at the end of the pump, ensuring that during applied acceleration forces the pump is less likely to move. Furthermore, the pump is attached to the support structure and pallet modules by bolts in the frame of the pump. Which with the support at the pump house, and the beam at the back, fixates the pump.

There are three different materials that are suitable; bamboo, pine and plywood. All the three material are fulfilling the durability requirements and will make one pallet module weight less than 20 kg.

The developed package concept is fulfilling most of the requirements identified during the product development phase. It is not possible to modify the length of the sides except when it is made. When an order for a pump arrives, the height of the pump must be specified for the sides to be appropriate length.

9.3   Summary of Effect on Production

Proposal for implementation of the package in production leads to changes in different areas. The main areas affected by the changes are packing station, planning and kitting station. The implementation of the package will be split into two areas, where the pallet modules and support structure is introduced in kitting and the sides, corners, fastening and roof is introduced at the packing station. Leading to pump assembly is being done on the pallet it later will be shipped on.

Using categorization of pumps and serial numbers helps understanding amount of modules needed for each pump. It also decreases amount of variations in the information as during planning they are putting orders for a pump in a group, and not individual pumps. Making it less information that the people handling the orders have to process.

After the pump is assembled on the pallet it is delivered to the packing station. Where the plastic is put on the pump before assembly of the rest of the package is done. This consists of assembly of the sides, roof, fastening and roof. All the modules is delivered to the packing station without any need of modifications.

Internal logistics become important for the concept to work efficient. Where a sequential delivery of modules to both kitting and packing station is proposed. This will ensure the correct amount of modules for the package arrives in respective station at the same time as the pump is. The proposed solution is suiting just-in-time production, or be adapted during a transition phase and planned demand for couple of days.

After estimations about time consumption regarding the new operations connected to handling the package the results show a difference in output. 2.8 to 3.4 times current output potential is expected after implementation of this package solution. Reducing time handling the package to 29.6 percentage of current time consumption. Furthermore, resources currently spent on materials and operators building the package will be freed to assist in other operations.

10 Discussion and Ethical Considerations

This chapter covers different point of discussion regarding the project and its potential to improve the current situation for Metso. But also the role of this project in future research and a discussion about ethics and social impact of this thesis.

10.1 Method

The methods presented in the theory chapter is modified to suit the challenge of this project. As the project has two areas of focus, and neither method have multiple focuses it needed some adjustment. The product development follow Ulrich and Eppinger, Liedholm and Ullman's methods which are adjusted to suit each other and the project. The Ulrich and Eppinger's method is the foundation upon which the other methods is applied. Ulrich and Eppinger's method suits product development well as it is advocating for an understanding of the area where the product should be applied. It relies much on the stakeholders being asked and information gathering from interviews and/or surveys. When in a production setting with experienced operators this is good, as the understanding of the processes, operations and products is very good. However, there is limitations of knowledge in this phase. As the operators, and organizations at the office does not handle the global shipping, it is limited knowledge regarding shipping and its standards, regulations and legislation. Further, this leads to applying Liedholm's method, which analyzes competition and how it is done today more, compared to Ulrich and Eppinger. This helps structuring the data gathering in its initial phase, where Ulrich and Eppinger's customer needs is used for interviews and Liedholm for analyzing the industry. They are then gathered in the interpreted needs table, which later translates to requirements.

Ullman's method is not used much in the project, but has interesting way of iterating the processes and steps during the development. This can be applied without referring to Ullman but the theory about it matches the challenges well in this project. As the project risking becoming very large, it is important to iterate, primarily the requirements process, to not include areas which are outside of the scope. To verify that the process has been done correct is also an opportunity to structure the work.

The adjustments to the methods are primarily Liedholm's design criteria list and function analysis. The design criteria list helps the project to structure ideas and current solutions in the market. It is making use of important functions, and then looking for solutions to the functions. This help understanding the important abilities of the product, and what solutions exists and what ideas that can be implemented for each function. The project is conducted by one person, and in this stage it is important to implement a structure which supports the development of a solution, and keep that unbiased. But also for understanding of the area which the project is focused on. The philosophy of the design criteria list is still applied, to keep the solution unbiased towards any solution but remove the obvious bad ideas.

The function analysis is also altered to suit the project, and primarily to include the production parameters in the product development. The analysis of the use of the product is done from the products life cycle during use. During the life cycle of the product, this has been used to explain the black box in more detail and how the product will transform in different operations, but also support transformation in other. In the context of production operations, and which operations is connected to the product is important information trying to reduce time handling the product. Function analysis is because of this used as a tool to analyze the products role in production, and what support systems is needed in different operations. It also includes the phase of use, where the product has left the factory. This is to ensure that phase is not neglected.

10.1.1 RQ1: Information Needed to Develop a Target Specification for a Product used in Global Shipping

While a summary can be found in chapter 9.1, the information needed to perform this project spans from standards to experience. Technical specifications are easiest to get information about from standards, regulations or legislation which often have a clear definition and explanation of why. Information about this is of the highest importance to gather and understand. Without fulfilling the standards, regulations and legislation the solution will be worthless and never have any chance of success. The standards covers materials that the package is built of, how they perform in different transport units, safety for operators, space utilization and how to pack different cargo. To conclude, there are rules or guidelines for almost everything. Which can be overwhelming, but important is to have clear understanding about what it is that should be shipped, to where and via what transportation. This narrows down the search of information to relevant parts.

This project focuses on pumps, which is a heavy product shipped over long distances. Because of this the focus is on understanding standards, legislation and regulations for shipping heavy cargo in different transportation units. Transportation by sea is most demanding on the package, both from forces applied but also from a regulations perspective. Due to this, it is the main focus to ensure that the package will fare well during transportation by sea.

10.1.2 RQ2: Production Analysis Methods in Product Development

During development of a product which aim is partly to make production more effective, there is a need for understanding the production. The difference between doing market research and a value stream mapping is not that big, considering the conclusions. The value stream mapping is analyzing and presenting what actions that are classed as wasteful actions, and what are value adding. This indicates potential, both in production and product development. When identifying a waste stream, a production technician may try to solve it by change of flow or remove that waste stream. But combining it in product development, the wasteful actions presents an opportunity to add functions to a product which can support production by making such actions not needed. It also supports when analyzing how the product should be implemented. As there are always prob-

lems understanding how a customer will use the product. With the help of value stream mapping, the product can be developed to suit current or wanted production.

Group technology is another powerful tool when developing products which needs to suit other products with high variation. This was essential in developing a modular design. Group technology categorizes the products by certain important functions, and presents similar products with less variation. Which is, during development of a modular product, very effective. Group technology in product development should not always be applied. It needs the right settings to support product development. The variation must exist but also similarities, even though the similarities may not be geometrical. For example, if a company develops different products with no geometrical similarities but it is possible, by design choices, to have similar manufacturing methods. Group technology will categorize the products or concepts relative to their manufacturing methods. Making choices early in the product development process.

10.2   The Concept

The concept presented is intended to be used for shipping and handling Metso's VASA-line of pumps. The VASA-line of pumps is not their newest line, and was developed before the use of computerized aids for drawings. Leading to a shortage of drawings and 3D-models of the pumps, which is an issue during development of the package concept. However, it needs to be verified before full implementation. It is developed with durability in mind, because of the heavy products that should be loaded into the package. The pallet module is the critical load bearer, as the pump is fastened into the pallets with bolts. It has three beams at the bottom, which all bear the load of the cargo. But also bear the load during lifting operations. Durability calculations will need to be made in greater depth, as current calculations is simplified. They are however backed by the stress simulation, which indicates that the current design will hold the forces applied.

Another critical part is the connection between the pallet modules. During lifting operations the forks of the truck, or the straps, will apply an evenly distributed force over the contact area, over multiple pallet modules. And with help of the overlapping modules into each other, support structure and frame of the pump, the modules will bear the weight.

As the pump is proposed to be introduced at the kitting station, pump assembly will be done on the assembled pallet and support structure. This leads to an investigation about how the support structure perform in pump assembly, and if it is hindering operators to perform certain actions. However, it is desired to have the support structure as it is because of the increased safety it offers. But it is possible to adjust it to suit pump assembly better.

A modular solution is developed due to the variation in size of pumps. The flexibility could however be accomplished by pallets which are adjustable in size without a modular solution. This was considered during development, and some concepts where developed. The conclusion from those concept is that moving parts

in a solution which will bear weights up to 9.5 tonnes and be subject to acceleration forces have a greater risk of failing than a solution without moving parts. By introducing moving parts, cost also increases as the solutions considered requires very strong materials which will have critical impact on performance. However, some inspiration can be taken from the design iteration phase. As the pallet modules have a weakness in the connection between the pallets, reinforcements can be placed where two pallets meet in form of a metal strip. But the solution should work without needing reinforcements like this.

The cost of building the modules have not been analyzed but can be argued to be more than a standard EPAL1-pallet. And it probably is, but in this scenario with a low number of the pumps being able to use EPAL1-pallets, this arguments have no substance. This is presented as a further study, but there are possible arguments for and against. The cost should be compared to building the pallet and the material use and other costs during this operation. The modules are standardized, except for the height of the sides. This means theoretically that this concept have potential to be mass produced in a non flexible production, reducing cost of producing the modules. If the height of the sides can be categorized by group technology, it will further reduce variations of the height of the sides. To do that categorization, there is a need to standardize what motors is used on the pumps as they are the main issue when determining height of the sides.

Possible challenges for the concept is to verify its durability during shipping. It needs to be tested in order to be confident in the conclusion that it is safe. However, if it is, the potential is there to change how pallets are used. Creating a pallet which is modifiable, and verified to suit a lot of the products being shipped creates strong arguments. Comparable to directives, where standard sub-solutions can be used to reach a verified solution, the pallet modules can be a standard solution of where different number of modules reaches a verified solution for a specific size and weight.

10.2.1 RQ3: Requirements for Global Shipping Effect on Ability in Production

The requirements have little effect on the ability in production. If comparing to a package developed to suit domestic shipping, the package is more robust as domestic shipping usually do not use transportation by sea. But this robustness does not impact production negatively, as it makes the package more durable. Four assembled pallet modules, with the same size as an EPAL1-pallet, have higher weight which affects handling of the pallet. But one modules weight is below 20 kg, making it possible for an operator to handle it without lifting aid. This is not the case with the 25 kg EPAL1-pallet. After assembly, the pallets weight will be higher compared to what is used today, but the handling may be better as the pallet can be built without needing lifting aids.

Adding the fastening modules is an effect of the requirements of global shipping. There is a need to include securing possibilities to the package so it does not move around within the transportation unit. However, it is a small effect as the actions related to the fastening modules take almost no time compared to the other actions.

10.3   Implementation in Production

The proposed implementation in production tries to offer an efficient solution to material and information flow. A proposal for implementation of the concept in production is presented in chapter 8. It is using lean principles to reduce wasteful operations and becoming more streamlined, reducing need of storage and unnecessary actions. Outsource building the modules of the package frees up time, but also enables a different flow of the package modules. The pallet modules and support structures introduction at the kitting station adds actions in the kitting, but as the actions introduced does not take long time to do, it is deemed as a good solution. It is however interesting to analyze the difference between assembling the pallet modules, compared to receiving an assembled pallet. They save time, 6.3 minutes, not doing assembly of the pallet modules. And 6,3 minutes may not sound as much, but adds up to around 27.5 workdays per year if Metso are producing the same amount of pumps as they are today. And if they were to fully utilize the potential output of 3.4 times current output, this would lead to around 93 workdays per year which they would spend on assembly of the pallets. However, the cost of purchase and shipping assembled pallets must be put against the cost of doing the assembly.

The estimation is calculated with data from one operator working in the process of handling the package. The increased efficiency and potential output is also only considering one operator per station, i.e. one in kitting and one in the packing station. No data is gathered about the time it takes to kit a pump order, but the reduced time in handling of the package leads to more operations at the kitting station. The increase of operations at the kitting station creates demand of a line balancing for the entire production. It could be possible that the kitting station becomes a bottleneck due to this. However, as a lot of resources is freed in the packaging station, some of that can be used in kitting. If one operator would assemble the pallet modules and support structure, they would be able to assemble 47 pallets and support structures a day, or 11 746 pallets a year, which is far more than current need of Metso. Leading to the conclusion that this will not be a problem. It will however need an analysis of how the operations should be balanced to optimize efficiency.

Analysis of production has been made in terms of lead times of handling the package and at the packing station. This is primarily because data does not exists to calculate takt times or lead times for other stations, nor does data exist to see at how they are utilizing the resources available. This limited the possibilities regarding analysis and comparability when proposing how to implement the concept in production.

The package is taking a bit more place than a regular pallet, which makes it a bit harder to store the pallet in regular pallet racks. But as the current solution includes a lot of different pallets used, it will be better to have standardized widths of the pallets, actually making it easier to store the pallets.

10.4 Concept in Shipping

The concepts primary function is to move the pump from the factory to end user, and how it is performing in shipping is essential. The concept is developed to follow standard sizes of pallets which is used today, which ensures that planning the use of space in the CTU will stay close to what is already is. Regarding space utilization, this concept ensures that no pump packed take a lot more space than needed. One example is group 1, see table 15, where the pumps only need half of an EPAL1-pallet, and is today delivered on a EPAL1-pallet. Those pumps will now only use half of the space, thus avoiding cost. However, as the pallets are a standardized size, they will occasionally be too large. But when analyzing the pump sizes, the biggest difference between the pumps width and width of a package is a total of 37 cm, or 18.5 cm on either side of the pump. While this is a bit too much, the majority is around 10 cm on each side. Some space between the pump and the side of the package is preferable, acting as a safety if it were to crash in to something.

The fastening modules helps securing the package in the CTU, and is giving support during acceleration forces applied on the package. The modules are secured in the pallet for extra support, but needs to be tested to be verified. However, there are a few different alternatives to consider. Having the fastening aid at the sides, but this would have created demands on the sides which would have been hard to fulfill without creating a much more robust design. The robust design increases cost but also ease of handling, as it needs to be heavier or of a different material. Choosing a lightweight and strong material is associated with increased cost. Furthermore, could a fastening aid go through the pallet. Which would mean that the majority of the lateral forces would be hold up by the fastening aid itself, and the securing straps. But it needs another hole through the pallet which would cause the load bearing capacity to drop, risking failing the pallet during use.

Stackability was an early focus of the project as the potential is clear. Is it possible to stack packages can you use the space more efficiently, thus reducing cost and environmental impact. However, analyzing the sides and how they must be constructed for another pump to be stacked it leads to a need of stronger sides. Either by changing material or design. Both would lead to similar results as the fastening modules, either more expensive or heavier.

10.5   Ethical and Social Considerations

The project is developed to support the ever going technical and social development. Within the scope of the project lies potential effects on the environment and humans. Safety is one aspect which is covered in the report and is very important for people using this product. Standards and legislation exists which needs to be followed, but the product is used also used in production setting, moving products mounted on the pallet. The developed pallet will standardize, not only the pallet used, but the handling of pallets. Standardizing the way of handling pallets will reduce learning time and make operators used to that sort of pallet. Currently it has happened, and is at risk of happening again, accidents when pumps have fallen of the pallet due to a combination of poorly placed pump, and poor use of pallet. Accidents like this can be fatal, as the cargo weight in this case can be very heavy. Making sure of the placement of the pump with help of the support structure will reduce the risk of a pump falling of the pallet. Also making sure that the centre of gravity is not close to any edge of the pallet will reduce falling risk. The choice of material also correlates to the operators safety, or reducing risk of injury over time. Current pallets weight is approximately 25 kg, which demands the operator to use a lifting aid to not get injured. With pallet modules which weight is below 20 kg, the operators can handle the pallets in a safe way without needing a lifting aid.

Increasing efficiency in production is often connected to something positive, but it is often connected to resources being reallocated or removed. It is a possibility that this solution will remove work opportunities at Metso's factory in Sala. This is the sad reality of trying to be more effecient but in order to continue to exist as a organization and employer, companies must strive for gains in efficiency. However, reducing lead times and increasing potential output will not necessarily lead to loss of job. This can instead be a possibility for the company to sell more products, or relocate resources from one area to another to improve the organization. It can even lead to more opportunities long term, and be beneficial to society.

The packages will be used one time because of the infrastructure needed to gather the packages does not exists. This has negative effect on the environment as the packages have potential to be used for much longer. It is not good utilization of materials used in the pallet. It would however, if successful and a large fleet of these package modules exists in the market, have potential for a longer life. The packages can be used again by the receiver, and modified to suit their needs, but there are limitations to what they can build only receiving the packages.

11 Conclusion

The product development is supported by production analysis methods through the entirety of the project, and even though the product development phases represent a majority of the data gathered it would not be possible to conclude the target specifications without the production analysis. Production analysis methods support the gathering of data for a product developed and primarily, the gathering of information about the environment the product is deployed in. To not only rely on customer statements and hidden needs is a real advantage, where the requirements are specified with the help of proven analysis methods of the area which the product should be deployed in.

The proposed concept and implementation of it have the potential to increase output of pumps to 3.38 times current output. Which is a major improvement compared to the current situation. The concept has potential to be used in a wide variety of products, and is not limited to bear only pumps. However, there is a need to verify and perform testing of the concept. It is also important to do a economical analysis, to calculate profitability. It is concluded however, freeing up resources corresponding to two thirds of current time handling package, that the concept has potential to be a profitable solution.

The requirements for global shipping affects the products ability in production. It adds operations, and by adding operations, increases time handling the package. If the product is to be transported on sea, it often needs a box which requires sides, corners, roof and fastening. Of the 31.7 minutes it takes to assemble a package, 18.1 minutes is handling the sides, corners, roof and fastening, which is 58 percentage of the total handling time.

Developing a package for global shipping requires knowledge about standards, legislation and guidelines. But to simplify and make the process efficient, understanding the challenge for what that specific cargo needs regarding package is crucial. Develop a package for one of the most demanding countries will ensure that the package fulfills most of the other countries' requirements as well. Furthermore, it is not only the legislation and regulations which will be fulfilled, the package will probably be safe and environmentally safe if this philosophy is applied.

12 Further Studies

This chapter covers further studies which should strive to continue the development of the concept and the implementation of it.

Durability testing needs to be done to verify the packages possibility to bear different weights. It is suggested to verify the modules for different configurations, for example, if 6 modules are used it can bear X kg of load. This will ensure there is a standardized solution, which can be built into different configurations to suit different needs. It is also important to further study the fatigue strength of the material and joints during transportation, because of the stresses and strains from the transportation method.

Broaden the perspective of cargo placed into the package. It has no limitation to only be used for VASA-pumps, but can be implemented in all different industries. The potential to use this concept over current industry leading solutions needs to be analyzed to see the potential of a wider implementation.

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Appendix

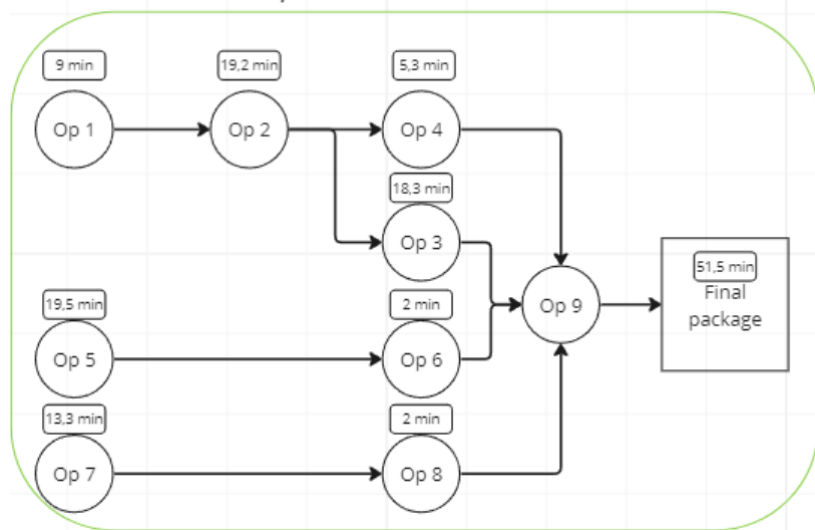## Appendix 1 - Line Balancing in current setup

Figure 42: Line balanced and how long time it would take to produce one package in that time.

Appendix 2 - Checklist for the construction criteria list

1. **Function:** What is it going to be used for?

2. **Function deciding abilities:** Limitations from production, or certain performance it needs to achieve.

3. **Abilities during use:** Where and how is the product used, which stresses and strains must it endure to work in such conditions. Does it need to be maintained?

4. **Production abilities:** Will the product be able to be produced with current production set up? Is there need for a third party to produce or buying a new machine?

5. **Distribution abilities:** How will the produce be transported? Does it need assembly after delivery or should it be stored?

6. **Delivery and planning abilities:** What volume should it be produced in? Should production happen in batches or single pieces?

7. **Safety and ergonomic abilities:** Is the product safe and ergonomic to use?

8. **Visual abilities:** What are the design elements that needs to be considered? Is it sensitive to fashion trends?

9. **Legal abilities:** Are there any regulations or legislations that the product needs to fulfill?

10. **Economical abilities:** Which cost is accepted regarding production, maintenance and end-of-life treatment.

11. **Recycle abilities:** What is the end-of-life potential for this product? Is it able to prolong the life cycle? Should it be disassembled?

12. **Ecological abilities:** Material use for the product and its effect on the environment. Is it hazardous or hard to mine, contributing to large emissions?
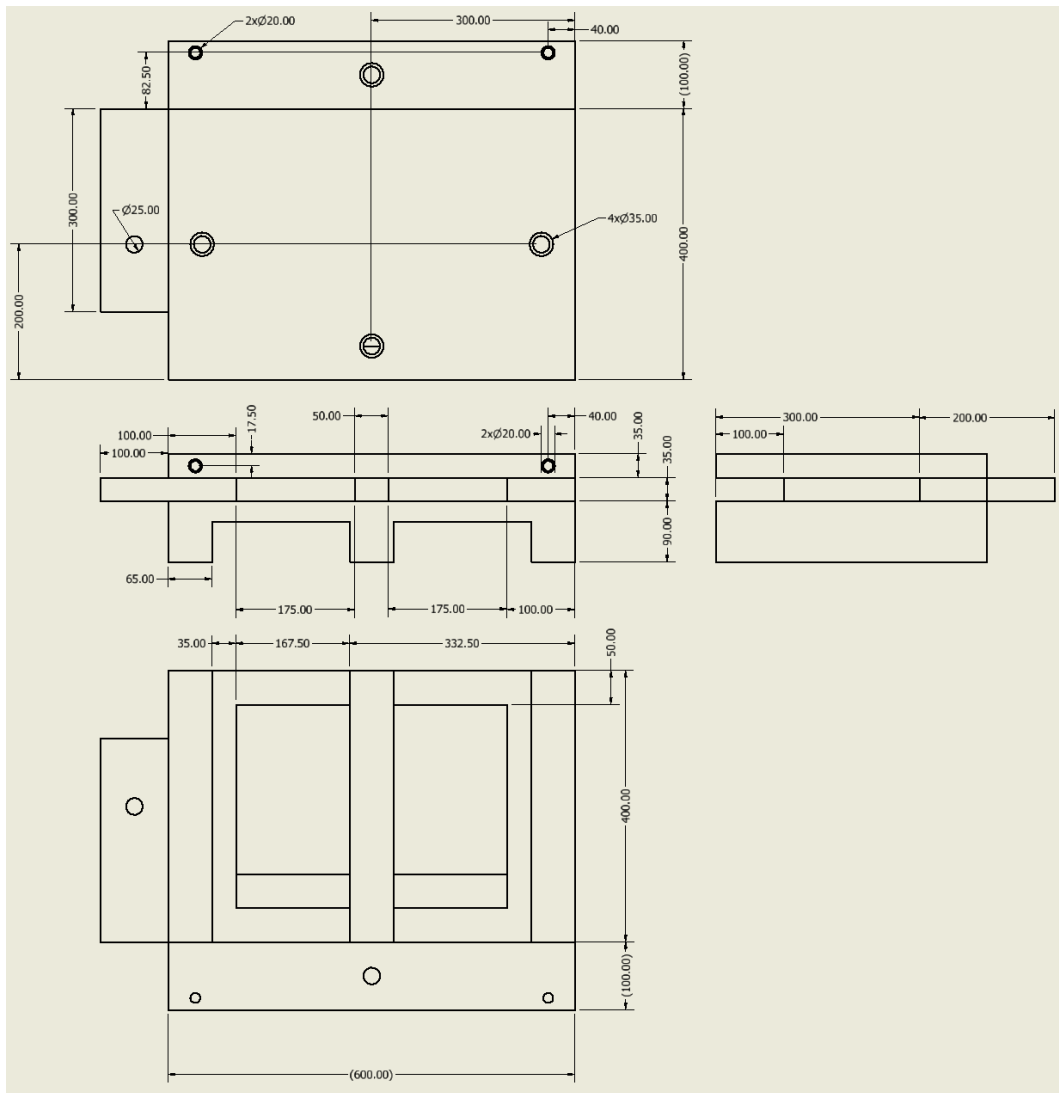
Appendix 3 - Drawings for pallet module

Figure 43: Drawings for the pallet module