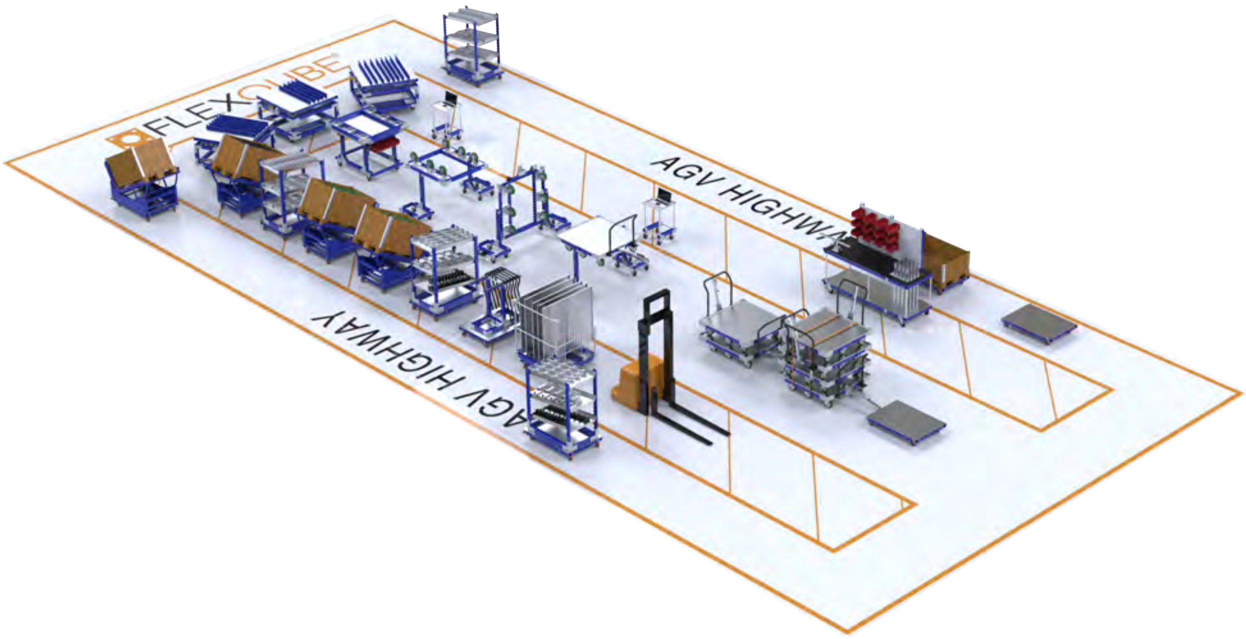
CHALMERS
UNIVERSITY OF TECHNOLOGY



Development of an Improved Manual Assembly Concept for Industrial Carts

Master's thesis in Industrial and Material Science

JOHAN SKOG
TOMMY SÜLD

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Master's thesis 2018

Development of an Improved Manual Assembly Concept for Industrial Carts

JOHAN SKOG
TOMMY SÜLD

Department of Industrial and Materials Science
Division of Product Development
Chalmers University of Technology
Gothenburg, Sweden 2018

Development of an Improved Manual Assembly Concept for Industrial Carts
JOHAN SKOG
TOMMY SÜLD

Supervisor & Examiner:
Johan Malmqvist, Department of Industrial and Materials Science

Master's Thesis 2018
Department of Industrial and Materials Science
Division of Product Development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: New Flexqube Assembly Concept

Printed by Reproservice
Gothenburg, Sweden 2018

Development of an Improved Manual Assembly Concept for Industrial Carts
JOHAN SKOG & TOMMY SÜLD
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

Flexqube is a fast growing company which develops and offers flexible industrial carts for material handling applications using standardised building blocks. Due to the fast growing number of customers, Flexqube has identified the need to streamline their assembly process in order to meet the demand and to lower costs. The purpose of this thesis is, therefore, to identify shortcomings in the current assembly process and to develop a new near-future system level assembly concept which will increase the productivity of the assembly process.

The thesis started with an exploratory literature study and an empirical study which included interviews, study visits and test assembling at both of Flexqube's current assembly plants. The data that was collected and analysed during these stages laid the foundation for the solution development and evaluation. These solutions were then evaluated in a proof of concept, to see whether the concept was an improvement or not. The result is an improved system level assembly concept along with newly developed assembly stations and material presentation carts. Improvements have been made to productivity as well as ergonomics. The proof of concept showed a 34 percent decrease in total assembly time compared to recorded videos of the current assembly process. A comparison with solely isolated assembly operations was also made through the use of standard work sheets. This comparison showed 23 percent decrease in assembly time. In addition to the improved productivity, the gain in improved ergonomics was also a success. The concept eliminated many of the poor assembly operations seen from an ergonomic point of view.

Keywords: Flexqube, assembly, process, concept, lean, flexible, streamline, cart

Acknowledgements

First of all, we want to express our sincere thankfulness to Per Augustsson and Flexqube who believed in us and offered us the opportunity to write this thesis. Even though Per is very busy he always takes time to help and his experience and guidance have been a great contribution to this thesis. Also, a great thank you to the rest of the team at Flexqube for answering our questions and helping us towards a better result.

We also want to thank professor Johan Malmqvist who has been our supervisor and examiner during this thesis project. Johan has been available and supportive at all times and has helped us by answering our questions with his objective and fact-based approach.

A special thanks to the employees at AMC in Georgia, USA, that showed us great hospitality and collaboration which facilitated the test assembling. A special thank you to Wesley Worthen and Jeff Watson who made our stay the best possible. Also a special thanks to Åsa Engström and the rest of the employees at WTAB for a good reception and cooperation during our test assembling.

Johan Skog & Tommy Süld, Gothenburg, June 2018

Contents

List of Figures

List of Tables

1

Introduction

The following chapter is structured as follows: first, a background that describes the situation of the company and the problem analysis. Secondly, the aim of the thesis is clarified followed by the intended deliverables and delimitations within the project. Finally, the outline of the report is reviewed.

1.1 Background

Flexqube is an international supplier of modular and robust carts for material handling. The company was established in 2010 with the ambition to create a competitive and flexible alternative to the traditional welded material handling carts. Their business aim is to facilitate the internal logistics and material handling for companies. This is performed by modular carts and building blocks, an innovative design process and high competence within internal logistics. Flexqube often refers to Lego or Mechano in order to describe the idea of the assembly concept. In Figure 1.1 one tugger cart and one shelf cart is illustrated, which were Flexqube's most sold variants in 2017 (Flexqube, 2017).

(a) Tugger cart (b) Shelf cart

Figure 1.1: Two of the most popular cart variants sold in 2017 (Flexqube, 2017)

Flexqube has developed a base of modular and smart building blocks which can be combined to create a customised cart for the customer. Flexqube is the only actor on the market offering this type of modular concept for heavy duty carts.

The four building blocks that lay the foundation of the carts are (see Figure 1.2)

1. *The Flexbeam*^{TM} - a high strength construction element used in almost all carts
2. *The Flextube*^{TM} - a steel tube commonly used as a construction element where the demand for load capacity is lower
3. *The Flexplate*^{TM} - mainly used to secure other Flexqube components together
4. *The Flexqube*^{TM} - an adaptable component normally used as an end piece on two flexbeams

All building blocks are constructed with a standardised interface which is used to connect the building blocks to each other. Regardless of how and what building blocks that are combined, a certain type of interface always ensure the ability to interconnect the building blocks. Flexbeam$^{\text{TM}}$ and Flextube$^{\text{TM}}$ are building blocks that are offered in several lengths in terms to enable the creation of different dimensions of the carts. The length of these components is standardised in length intervals of 70 mm in order to support the various combinations.

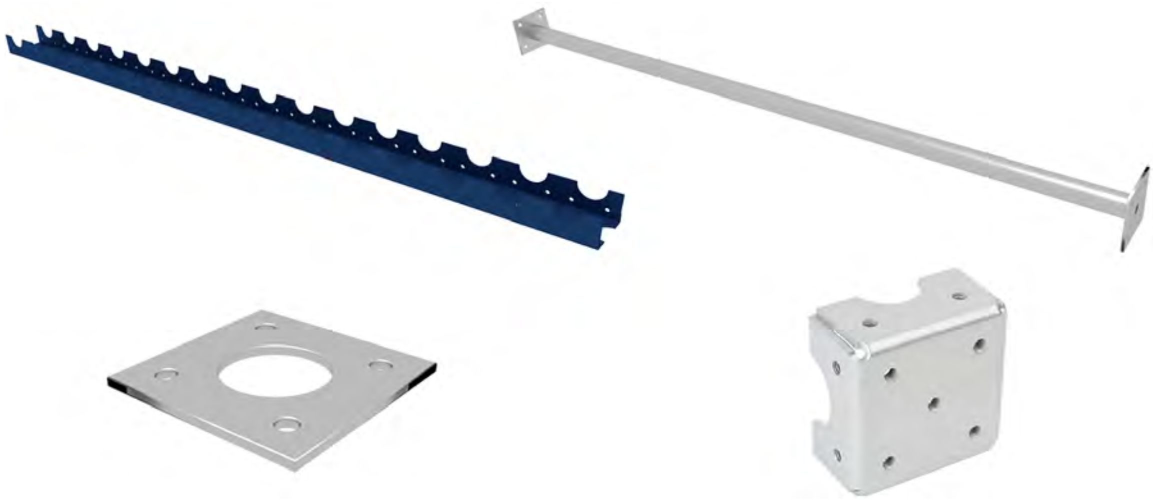


Figure 1.2: Examples of standard Flexqube components from the top left corner: Flexbeam$^{\text{TM}}$, Flextube$^{\text{TM}}$, Flexplate$^{\text{TM}}$ and Flexqube$^{\text{TM}}$

In addition to the four fundamental building blocks, about 1400 other components are available in order to enable customisation. Examples of components are handlebars, joints, shelves, floor friction brakes, wheel attachment boxes and casters, moreover, a wide range of fasteners are offered in terms to create a complete solution for the customer (see Figure 1.3). All complementary building blocks are also constructed with the standardised interfaces, enabling the integration of these parts into the cart. If the customer has demands beyond the existing component library, Flexqube are able to develop and manufacture custom-to-order components in order to meet the needs of the customer.

In contrast to traditional welded carts, Flexqube uses bolts and nuts to connect their building blocks into carts. This enables an easy reassembly of the product if the original purpose of the cart has changed. The company's aim is that the carts should be easy enough to reassemble and change so that the customers themselves can easily do it at their own location.

Flexqube uses manual assembly to produce the described concept and has identified a need to improve their assembly process. In addition, Flexqube foresees an increasing demand for their products and therefore must increase the efficiency of their internal production. Therefore, this thesis examines how a near-future Flexqube cart assembly concept could be designed in order to reduce the assembly time.

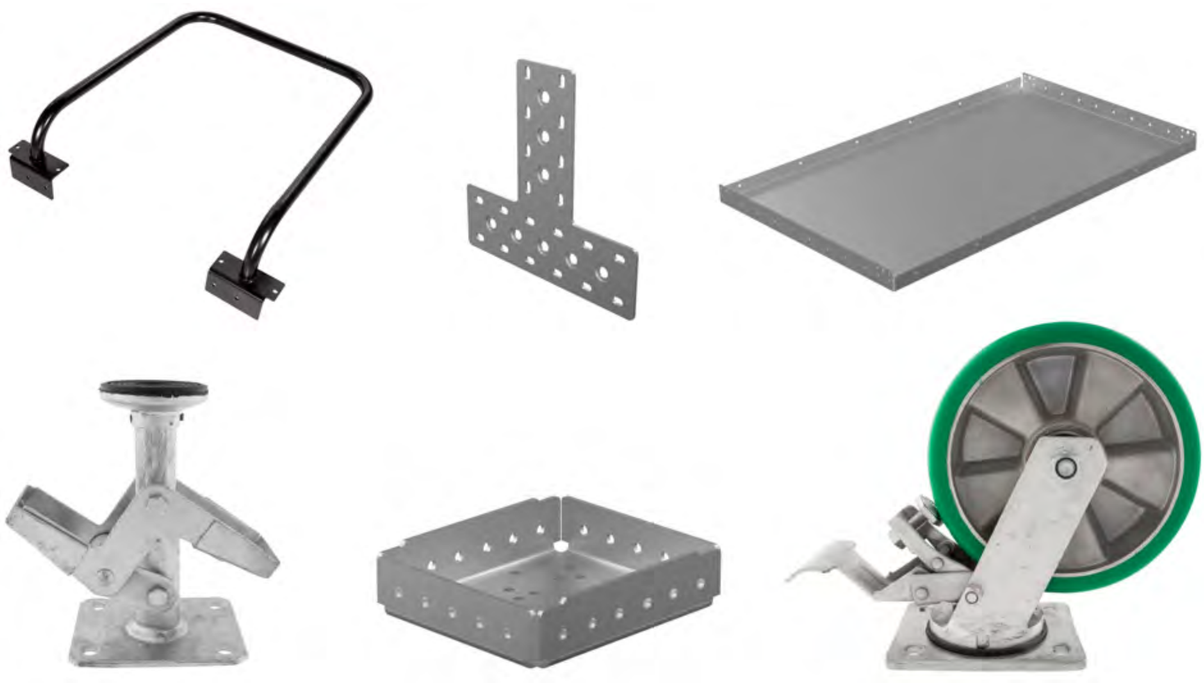


Figure 1.3: Examples of Flexqube components, from top left corner: handlebar, t-joint, shelf, floor brake, wheel attachment box and caster

1.2 Aim and Goals

The assembly in general accounts for approximately 50 percent or more of the manufacturing costs, as well as it has a direct impact on the product quality (Zhaa et al., 2001). Swift and Booker (2003) states that "about 50 percent of all labour in the mechanical and electrical industries are involved in assembly". The aim of this thesis is to come up with a near-future assembly concept that would increase the productivity of the assembly process, which would lead to reduced costs. In order to do so, the current assembly process will be investigated to identify what the current shortcomings are. From that starting point, improvements of existing faults and new ideas will be presented.

The goals of this thesis are to:

1. Identify and describe the shortcomings in the current assembly process
2. Shorten the assembly time of a chosen reference cart with at least 25 percent
3. Develop a flexible assembly concept which is insensitive for variation in carts, assembly location and takt time
4. Demonstrate a proof of concept of the improved assembly concept in order to measure if improvements have been made
5. Improve the overall ergonomics in the assembly and eliminate assembly operations with a high risk of musculoskeletal disorders

1.3 Deliverables

This master thesis will include several deliverables which are divided into two stakeholders, Chalmers and Flexqube. At Chalmers, the deliverable consists of the report in hand. In addition to this deliverable, the company also expects a mapping of the current assembly process, an assembly concept on a system level and a proof of concept (PoC), further described below.

Mapping of Current Assembly Process
An overview of the current assembly process that illustrates problems and opportunities in the current assembly process. The mapping will consist of one or several flowcharts, fishbone diagrams and lists of where improvements can be made for each step in the assembly process.

Assembly Concept on a System Level
A concept on a system level, meaning the inclusion of the assembly station where the carts are assembled together and the surrounding including a presentation of both tools and parts. The concept will be presented through the use of overview drawings and CAD renderings.

Prototype of Assembly Station
In order to evaluate the result of the assembly station, a prototype will be built made out of Flexqube components. The prototype will be built for the purpose of evaluating whether the ability of rotation will facilitate the assembling or not.

Report
The report in hand according to Chalmers guidelines. The report is the main deliverable to Chalmers.

1.4 Delimitations

Flexqube offers the customer the possibility to both assemble the solutions themselves or to buy preassembled solutions. When the customer assembles the product themselves, all components are sent along with instruction manuals. If the customer wants the product preassembled, the carts are sent fully assembled. Therefore, depending on how the customer prefers to purchase the solution, the assembly process may differ. The final result will not be focused on the assembly process from the customer's point of view, but rather the assembly process as performed by Flexqube (even though this might affect on-site assembling as well).

The prototype of the assembly station used in the PoC will be a simplification of the final assembly station. The prototype is only evaluated for its ability to rotate the cart during assembling and does not contain all necessary features to be used in the assembly concept.

The prototyping and testing of the new assembly concept could not be carried out in the real assembly line area, therefore a mock-up assembly line was created next to the real one with near to real resemblance.

Because of the difference in measurement units between the USA and Europe, the tugger cart which was used for analysis in the USA and the tugger cart used for the PoC are not identical. The cart chosen in the PoC is nearly identical and was the closest cart in shape and dimension that could be accessed in Europe. The cart assembled in Torsby did not have the sheet metal on top of the cart. Therefore, the assembly time of the top sheet metal was replicated from the assembly in the USA to the PoC time analysis. Both carts can be seen in Figure 1.4 (next page).

(a) Cart assembled in the USA during empirics

(b) Cart assembled in Torsby during PoC

Figure 1.4: Differences in carts

According to Ulrich and Eppinger (2012), a product development process follows a certain working flow, of which one is illustrated in Figure 1.5. This thesis work is not a pure product development project, but a project including mapping of the current assembly process and the creation of a new assembly concept and its surrounding on a system level. Therefore, the emphasis has been put on the first three steps in the product development process. This was also justified by Flexqube who argued that it will create more value for Flexqube if more time is spent on performing a PoC rather then to go into mechanical details. This will enable the concept to be proven before resources are spent on detail design.

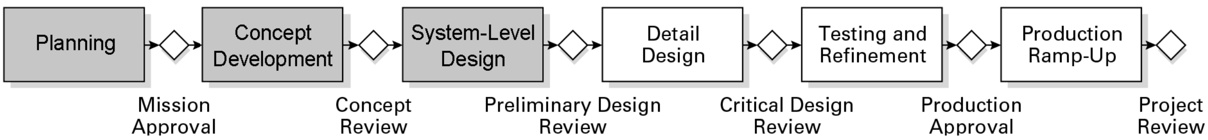


Figure 1.5: Generic product development process Ulrich and Eppinger (2012)

1.5 Disposition of Report

The following section describes and illustrates the disposition of the report in order to give the reader an overview of the report, see Figure 1.6.

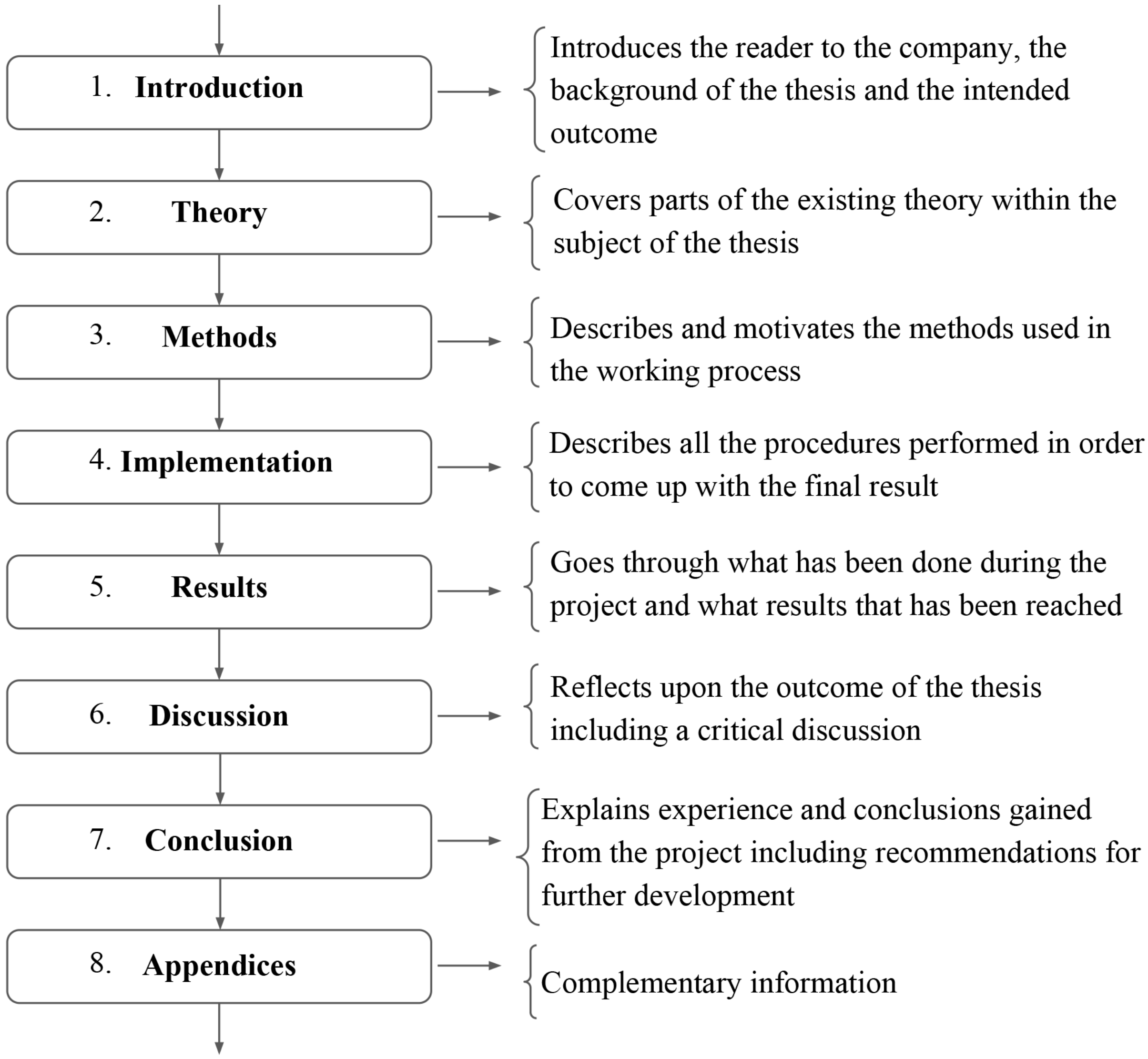


Figure 1.6: Illustration and description of the report disposition

2

Pre-study and Theory

During the theoretical study, the focus was to gain as much knowledge as possible in the theoretical field of assembly since it would enable a better understanding of the upcoming phases of the project. The theory mainly included books and papers connected to the following topics: design for assembly (DFA), design for manufacturability (DFM), lean manufacturing, lean six sigma, fastening methods, process selection, product development and production strategies. The following chapter will bring up existing theory within the most important fields of this thesis.

2.1 Manual Assembly Configurations

Swift and Booker (2003) describe manual assembly as "composing of previously manufactured components and/or subassemblies into a complete product...". Further, it is described as a process which is normally performed by humans, but might be supported by automated systems. Swift and Booker (2003) suggest three common manual assembly configurations, namely the following:

1. *Single-station* - one fixed assembly station that is dedicated to a certain task or a variation of tasks.

2. *Continuous* - several assembly stations are dedicated to a specific task where the working task is moved between the assembly stations without stopping (e.g conveyors).

3. *Intermittent* - several assembly stations are dedicated to a specific task where the working task is moved between the assembly stations based on a fixed cycle time or operation time.

Even though several assembly stations might be needed, Ortiz (2006) argues that in order to reduce movement waste, the travel distance should always be minimised (distance from start to end in the assembly). This allows for a more efficient usage of the space which can be adapted for e.g in-house machines or even be leased to third parties. Ortiz (2006) further states that a reduction of assembly stations is another approach to reduce movement waste and cost due to fewer workbenches, tools and space. On the other hand, Baudin (2002) claims that if a product can fit on a pushcart, the assembly work is possible to be split up into smaller sequences and pushed through several assembly stations. Lešková

(2013) says that an assembly line must be flexible and easy to reconfigure to quickly enable for new product variants in order not to lose production time. According to Baudin (2002), an ideal assembly fixture should allow the assembler to access all assembly work in an ergonomically correct posture, use both hands for work, be able to support bins for parts and fit several products.

The theory concerning manual assembly configurations helped to gain knowledge in standard manual assembly set-ups. This was considered as valuable knowledge since it is a prerequisite for all companies working with manual assembly.

2.2 Assembly Operations

Swift and Booker (2003) discuss several assembly operations. Below, a selection of these are described.

1. *Feeding* - is a synonym for what will be referred to as material presentation in this thesis. In other words, how a component is presented to the assembler. Common examples are regular storage bins, organised parts in pallets or magazines and automatic part-feeding

2. *Handling* - the actual handling of the material and the assembling of it. Normally hands, lifting aids and fixtures are used

3. *Fitting* - includes the fitting of components. This means both the parts that will constitute the assembled product and fastening components such as bolts and nuts. Fastening methods as screwing, electric tools and riveting are mentioned

4. *Transfer* - if the assembly requires several stations, the transportation in between the stations are referred to as transfer

Priest and Sánchez (2001) states that the fewer components within a product the better. Fewer parts mean a more reliable product since it will reduce the risk of failure in both manufacturing and assembly, it will also reduce the risks of e.g. late delivery and damages in shipping. In addition, it will lead to a reduced cost of inventory, material handling and other support areas. By this argument, Priest and Sánchez (2001) means that the optimal part count for a product would be one. Daetz (1987) came up with the following conclusions regarding adding parts:

1. The time and cost of assembly are about proportional to the number of parts being assembled

2. The cost of storing a part in a manufacturing system may range from $500 to $2000 annually, adjusted for inflation this sum is approximately doubled

3. The cost of finding a qualified vendor for a new part may cost up to $5000, doubled if adjusted for inflation

Priest and Sánchez (2001) do not only challenge the usage of components, but also the usage of fasteners. They argue that fasteners increase the risk of poor quality and exemplify a computer where 10 percent of all repair cost was related to fasteners. Priest and Sánchez (2001) further question the use of fasteners due to its cost and gives an example of five computers where the attachment of fasteners average a total cost of 10 - 27 percent of the assembly labour cost.

Through studies of assembly operations and configurations, a foundation of knowledge was laid which contribute to a greater understanding of the following studies and the overall methodology concerning assembly.

2.3 Material and Tool Presentation

In order for the assembler to maximise their efficiency, Lešková (2013) argues that all components should be delivered from the outside of the assembly area when re-supplying is done. Lešková (2013) recommends the usage of gravity feed bins, in order for the material to always be as close to the assembler as possible. Baudin (2002) says that other people than the assembler must make sure that all material is delivered to the assembly station, unpacked. Baudin (2002) further states that all material should if possible be presented to the assembler within arm's reach and oriented in such way that it is easy for the assembler to grab and place the component. Lastly, Baudin (2002) describes an actual example where a 30 percent net productivity was achieved by having a full-time picker serve two assembly lines with parts. The lines went from five assemblers on each to three assemblers on each.

When it comes to tool presentation, Lešková (2013) states that all tools should be placed in their own designated compartment, which should allow for easy access and insertion. This in order to reduce misplacement of tools. Both Lešková (2013) and Baudin (2002) argue that the tools should belong to the station and not the user. Also, they argue for storing tools which are used together next to each other.

By studying literature regarding material and tool presentation before implementing a new assembly concept, the new concept has been created to support the best possible presentation of tools and material, in order to streamline the process.

2.4 Cost of Assembly

Swift and Booker (2003) have come up with a model that calculates the cost of the assembly, see Equation 2.1.

$$C_{m_a} = C_1(H + F) \tag{2.1}$$

$$\begin{cases} C_{m_a} = & \text{Cost of manual assembly} \\ C_1 = & \text{Cost of labour} \\ H = & \text{Handling time (seconds), see Equation 2.2} \\ F = & \text{Fitting time (seconds), see Equation 2.3} \end{cases}$$

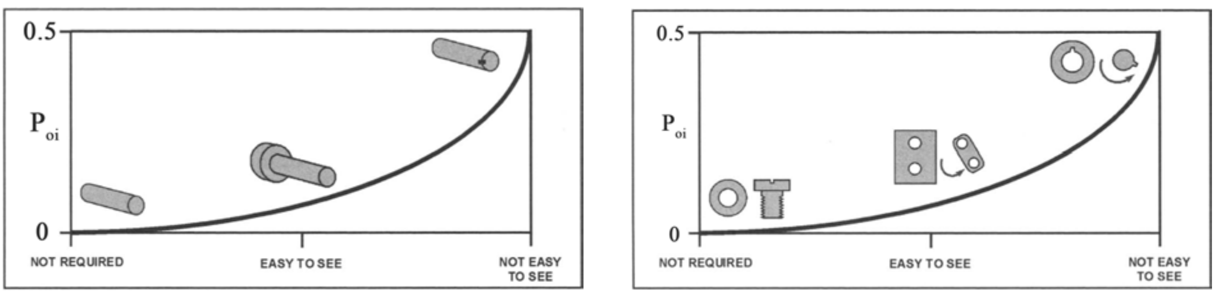
In order to calculate the handling time (H), Equation 2.2 is used (next page).

$$H = A_h + \left[\sum_{i=1}^{n} P_{o_i} + \sum_{i=1}^{n} P_{g_i} \right] \tag{2.2}$$

$$\begin{cases} A_h = & \text{Basic handling index, see Table 2.1} \\ P_{o_i} = & \text{Penalties for orientation, see Figure 2.1} \\ P_{g_i} = & \text{Penalties for general handling, see Table 2.2 (next page)} \end{cases}$$

Handling of component	**Basic handling index** (A_h)
One hand	1
Easy, e.g. one hand tool	1.5
Two hands required, heavy	1.5
Two people required, very heavy	3

Table 2.1: Selection of the basic handling indices A_h (Swift and Booker, 2003)



(a) End to end orientation

(b) Rotational orientation

Figure 2.1: Diagrams to determine the orientation penalties P_o (Swift and Booker, 2003)

Component handling sensitivity	**Handling sensitivity index** (P_g)
Fragile	0.4
Flexible	0.6
Adherent	0.5
Tangle/severely tangle	0.8/1.5
Severely nest	0.7
Sharp/abrasive	0.3
Hot/contaminated	0.5
Thin (gripping problem)	0.2
None of the above	0

Table 2.2: Selection of the handling sensitivity index P_g (Swift and Booker, 2003)

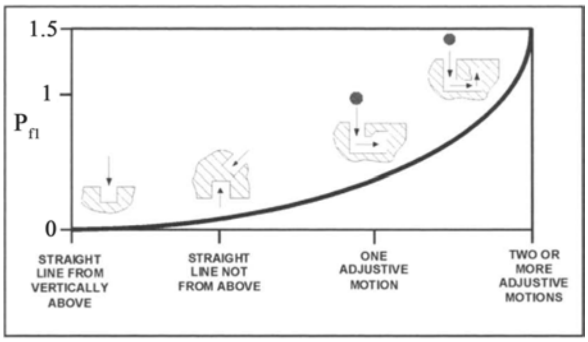
In order to calculate the fitting time (F), Equation 2.3 are used.

$$F = A_f + \left[\sum_{i=1}^{n} P_{f_i} + \sum_{i=1}^{n} P_{a_i} \right] \tag{2.3}$$

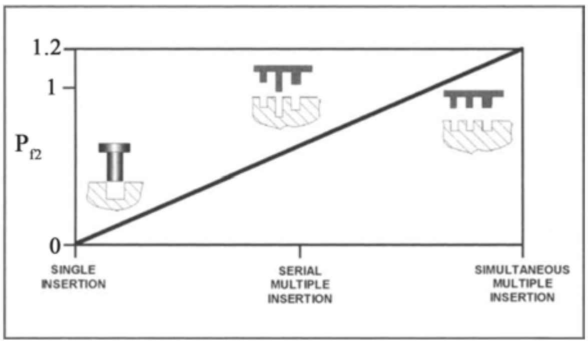
$$\begin{cases} A_f & = & \text{Fitting index, see Table 2.3} \\ P_{f_i} & = & \text{Insertion penalties, see Figure 2.2 (next page)} \\ P_{a_i} & = & \text{Additional assembly index, see Table 2.4 (next page)} \end{cases}$$

Assembly process	**Index** (A_f)
Insertion only	1
Snap fit	1.3
Screw fastener	4
Rivet fastener	2.5
Clip fastener (plastic bending)	3
Placement in work holder (P_f and P_a usually not required)	1

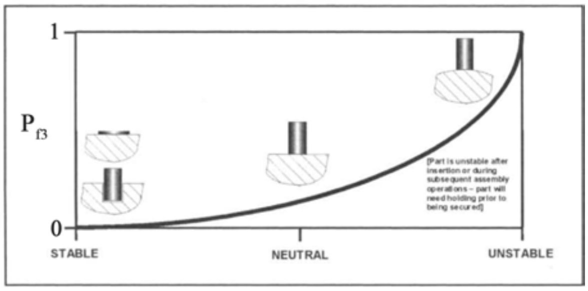
Table 2.3: Selection of the basic handling indices A_h (Swift and Booker, 2003)



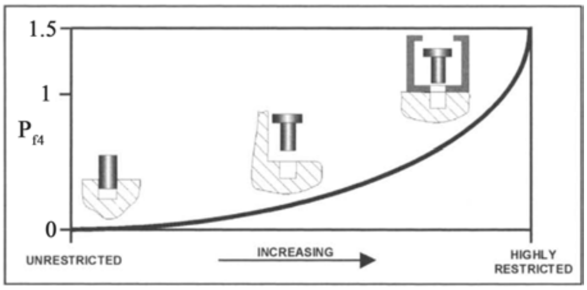
(a) Insertion direction



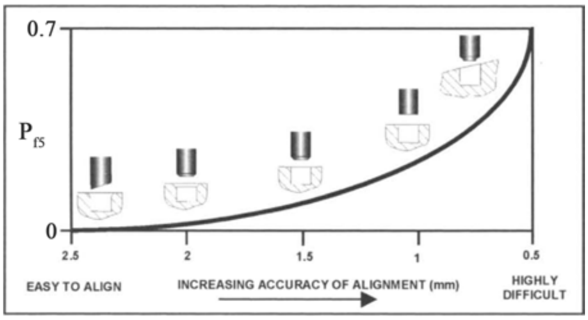
(b) Insertion collateral



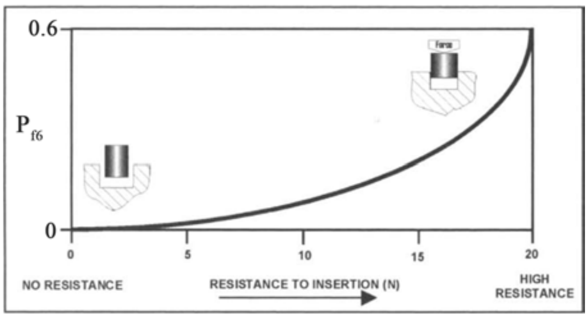
(c) Component stability



(d) Insertion access



(e) Insertion alignment



(f) Insertion resistance

Figure 2.2: Component insertion penalties P_{f_i} (Swift and Booker, 2003)

Additional assembly process	**Index** (P_a)
Additional screw running	4
Later plastic deformation	3
Soldering / brazing / gas welding	6
Adhesive bonding / spot welding	5
Reorientation	1.5
Liquid / gas fill or empty	5
Set / test / measure / other [easy/difficult]	1.5/7.5

Table 2.4: Selection of the additional assembly index P_a (Swift and Booker, 2003)

The study regarding assembly cost has shown the important factors that decide the cost of assembly. By paying attention to these factors when designing a new assembly concept, the assembly can be made more efficient and therefore lower the assembly cost.

2.5 Lean Assembly

A definition of lean is according to Bicheno (2004) "..to do more with less". It builds upon the Toyota Production System (TPS) which was developed during many years in the mid-1900's at Toyota, in order to competitively produce cars in large variation but in small quantities at manageable cost (Bicheno, 2004). This section contains some methods to find and eliminate waste.

2.5.1 The Eight Wastes

During his time as Chief Engineer at Toyota during the mid-1900's, Taiichi Ohno identified seven different wastes within production which exists in every level of a company (Ortiz, 2006; Bicheno, 2004). Waste is everything that does not add value to the customer and which the customer thereby is not paying for (Liker, 2004). According to Ortiz (2006); Bicheno (2004), one additional waste is commonly used today, the eight wastes are:

1. *Overproduction* - meaning that production is being made faster and in more quantities than needed. Overproduction can result in products with a higher level of defects, stress on workers and more material handling in inventory.

2. *Wait time* - is when an operator is inactive and can not proceed with their work activities. Examples of causes can be waiting for material, faulty machinery, waiting for another operator or poor communication.

3. *Transportation* - is the waste of material being handled ineffectively. For example being handled several times, unnecessary long distance to pick up material or through poor planning.

4. *Overprocessing* - are processes connected to the product which does not add value to the product. For instance, parts that are painted even though they are not visible to the customer or unnecessary part protection between stations.

5. *Inventory* - all inventory is a waste in theory, but in practice it is necessary. Parts in inventory increase cost, lead time and occupies space.

6. *Motion* - is a waste emerging at the workstation while assembling. Motion waste can be caused by misplaced tools, long distance to retrieve components or unergonomic assembly operations.

7. *Defects* - are waste connected to faulty components or products. The earlier a defect is detected the better. If a defect is found in a complete product in the hands of the customer the cost can increase several times and goodwill can be affected.

8. *Skills* - is the under-utilising of capabilities or lack of proper training.

2.5.2 Standardised Work

Moore (2006); Ortiz (2006) states that, standard work "reflects the current best, easiest and safest way to do a job". Ortiz (2006) states that standardised work is the process of finding the best procedure to accomplish a task, and then make sure that this procedure is used at all times, by all workers. Standardised work decreases variation within the process, facilitates performance measurements and provides training material (Ortiz, 2006; Moore, 2006).

2.5.3 Takt Time and Cycle Time

According to Bicheno (2004), a delegation from Toyota visited the Focke-Wulff airplane factory in Germany before the outbreak of World War II. They observed a concept where the planes were made according to a set production rate. This was later developed into takt time. Ortiz (2006) defines takt time as "..the time to complete a unit in order to meet the designed output of the process", where the output can be customer demand. Bicheno (2004) describes the takt time as "..the available working hours during a time period divided with the average customer demand during the same time period". Bicheno (2004) further states that the takt time is what decides the speed and rhythm of the production. According to Baudin (2002), the customer is not directly affected if the product is produced to takt time or not, although, it affects them indirectly by improving quality and delivery performance as well as lowering costs. Baudin (2002) further states that an assembly line should be designed for the minimum takt time (highest estimated demand), but is usually operated at a longer takt time, which is why the assembly line should be flexible in order to respond to large changes in demand. As can be seen in Equation 2.4, the takt time changes if either the customer demand changes or if the net available assembly time changes through e.g. the addition of more assembly workers (Baudin, 2002).

$$Takt\ time = \frac{Net\,available\,assembly\,time}{Customer demand} \tag{2.4}$$

In addition to takt time, there is also a cycle time. Cycle time is the actual time it takes to assemble one complete product or sub-assembly and varies between assembly stations and variants of products (Ortiz, 2006).

2.5.4 Increased Productivity

According to Almström (2015) who has been conducting studies concerning productivity within Swedish industry, there are three important factors to consider to increase productivity:

- *Method* - designing the workplace and its activities in an appropriate way from the start

- *Performance* - how long time assembly tasks actually take, in relation to how long they should take
- *Utilisation* - how large share of the working time that is strictly value-adding activities

Measurements made show that a 50 percent gain in productivity can be made by focusing on the utilisation factor alone. Working with all three, the gain can be even greater (Almström, 2015).

Knowledge gained regarding lean assembly has been of great importance to eliminate the presence of waste in the assembly process. Furthermore, literature concerning standardised work, takt time and increased productivity contributed to valuable knowledge when designing the overall assembly concept.

2.6 Ergonomics

IEA (2017) defines ergonomics as “scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance”. IEA (2017) further argues that ergonomics affect jobs, products and environments and its connection to humans. Below, physical and cognitive ergonomics aspects connected to this thesis are brought up.

2.6.1 Physical Ergonomics

According to a study performed by Falck et al. (2014), there is a strong correlation between quality errors and poor ergonomics in the assembly. The same study concludes that there are “..huge savings and increased profit margins to make..” and also good chances of increasing overall productivity by removing unergonomical work. This link between increased productivity and improved ergonomics in the assembly is also confirmed by Battini et al. (2016); Zare (2016). Battini et al. (2016) calls this link a “..win–win approach” as it also improves operational safety. Zare (2016) argues that many companies only see ergonomics as a tool to prevent injuries and not the potential productivity win and decreased cost. The most occurring injury among manual assembly is work-related musculoskeletal injuries (Battini et al., 2016). Berlin and Adams (2017) describe musculoskeletal disorders, or MSDs, as a disorder which can be caused by a variety of physical factors, and where the first signs are commonly pain, fatigue or discomfort. The consequences for the assembly worker is obvious, but for the company, a sick leave is equal to high costs. Berlin and Adams (2017) further states that the risk of MSDs can be avoided if workplaces are designed in the correct way by minimising e.g. incorrect working posture, heavy lifting and work which causes continuous load on tissue structures.

A cube model, first developed by Sperling et al. (1993), can be used to show the connection between force, posture and time. As can be seen in Figure 2.3, the risk of injury is not so high (green) if only one of the three factors is high, but if combined together (yellow and red) it can be dangerous and needs to be investigated.

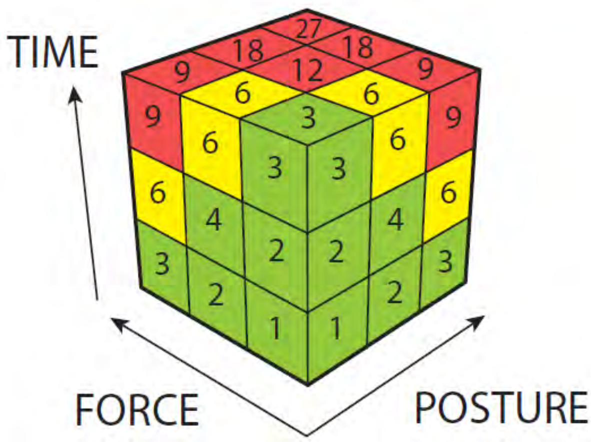


Figure 2.3: The cube model, illustrating risk level depending on combinations of force, posture and time (Berlin and Adams, 2017).

2.6.2 Cognitive Ergonomics

Cognitive ergonomics treats characteristics including memory, perception and motor response during human interactions. It affects decisions, stress, training, skill and mental workload (IEA, 2017). According to Zare (2016), the research within cognitive ergonomics and quality related issues are still scarce. Colour is part of cognitive ergonomics and can be used in many ways to capture attention (Leonard, 1999). Ortiz (2006) argues that bins containing specific items near the assembly line should be colour coded and labelled in order to reduce the possibility of errors and to make it easier to identify a specific item during assembly. Baudin (2002); U.S.Army (2000) also confirm that colour and labelling improves visual identification. Baudin (2002) continues to state that markings reduce the number of human errors and makes it easier to train new assembly workers.

The study concerning ergonomics has contributed to a deeper understanding of the ergonomic needs in assembly and how to prevent the occurrence of injuries incurred during assembly work.

3

Methods

The following chapter describes the methods adopted in order to conduct this thesis. In order to provide an overview of the methods, a process outline is illustrated in Figure 3.1. The left side of the image represents the different phases of the project, while the right side lists the intended outcomes of each phase. In the next upcoming sections, the method used in each phase is described further.

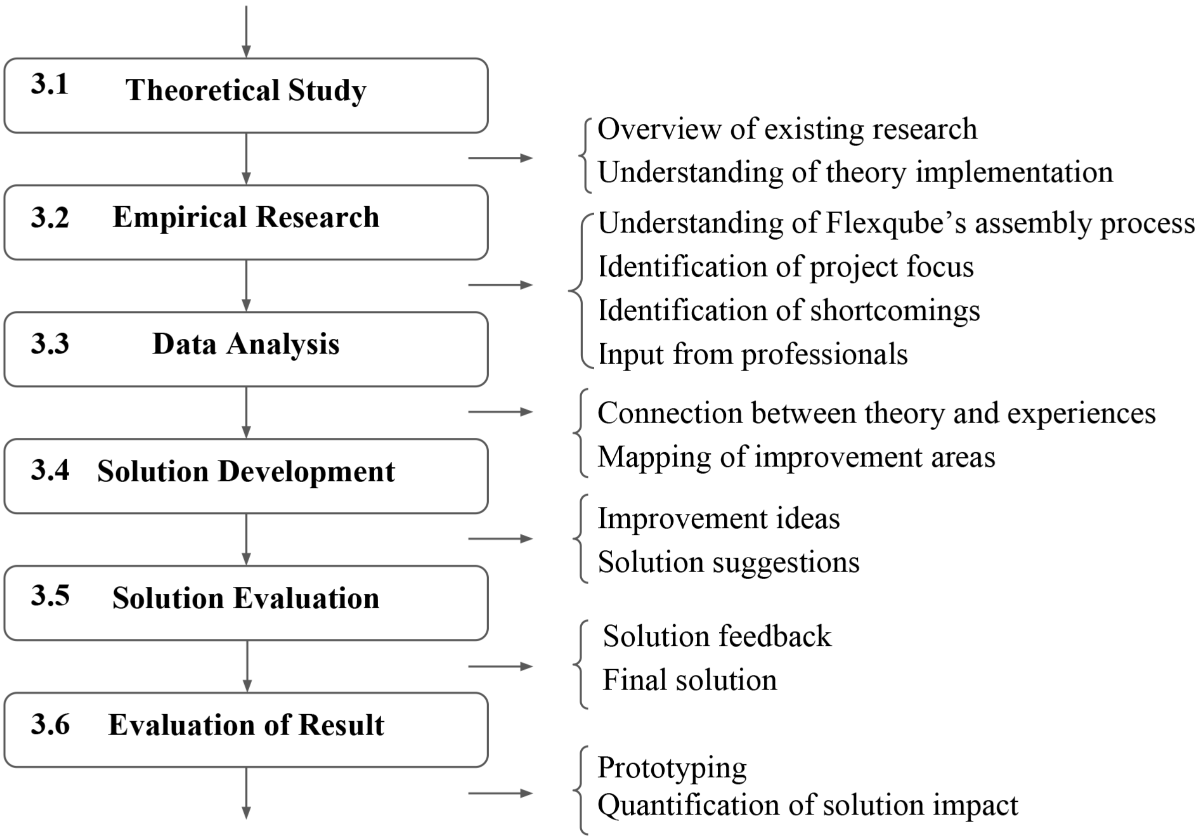


Figure 3.1: Process outline including the different phases and their outcomes

3.1 Theoretical Study

The initial phase of the project consisted of a study of state of the art literature on how to improve assembly processes generally. Denscombe (2014) defines the aim of a literature study as "...to arrive at a conclusion about the state of knowledge on a topic based on a rigorous and unbiased overview of all the research that has been undertaken on that topic". The process of the literature study was performed according to Kaya (2016), who suggests to the following outline: find papers, organise the papers, screen the papers and classify the papers. The literature that was investigated in order to reach an objective conclusion included books and papers. The databases Chalmers library, Proquest and Google scholar were used in order to find relevant literature. Also, experts from Chalmers were contacted for literature recommendations. The keywords used in the literature searches can be seen in Table 3.1

Assembly	Beams	Components	Design	Disassembly	Effective
Fastening	Ikea	Improve	Kaizen	Lean	Manual
Manufacturing	Mechanisms	Modular	Optimization	Process	Production
Reduce	Scania	Standard	Streamline	Time	Toyota

Table 3.1: Keywords used for literature search

3.2 Empirical Research

Gaskell (2011) defines an empirical research as acquired knowledge gained from own experience, observations and qualitative research such as in-depth interviews. In addition, an empirical study may also include measured data (PSU, 2018). This in contrast to a theoretical study which is based on just theory. The approach of the empirical research was mostly focused on Flexqube's in-house competence, data and experience. This included hands-on assembling of carts complemented with observations and interviews with personnel within the company. The purpose of the empirical research was to acquire an understanding of how the internal processes are designed as well as identify current shortcomings in the assembly process. Furthermore, the empirical research also consisted of a wider knowledge scan for assembly improvement strategies through the use of interviews and study visits outside Flexqube.

3.2.1 Interviews

Three different types of interviewee groups have been interviewed during the empirical research, see Figure 3.2. All interviews have been conducted through the semi-structured interview approach, which is both flexible and versatile (Kallio et al., 2016). Kallio et al. (2016) and Strande et al. (2014) further states that qualitative semi-structured interviews increases the validity and flexibility and makes the results more plausible. Due to low efficiency when transcribing interviews, Bryman and Bell (2011) have come up with an alternative method. The method is based on simultaneous notes of the sayings of the interviewee, which is verified by the interviewee at the end of the interview. This allows for the usage of certain quotes, which would be time-consuming if the interviews were to be transcribed. For more detailed information regarding each of the interviewees, please refer to Appendix A.

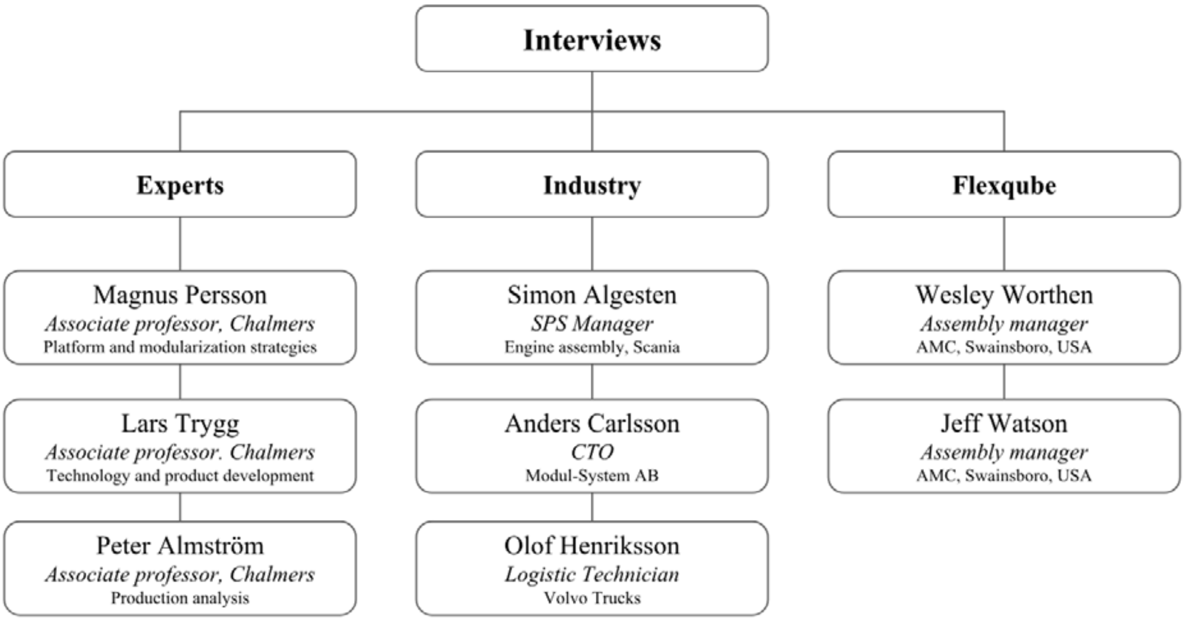


Figure 3.2: An overview of the conducted interviews

3.2.2 Study Visits and Observations

Study visits have been made to two companies with in-house assembly to observe and gain knowledge & inspiration of e.g. layout, ergonomics, methods, tool usage and part presentation. Robson (2011) claims that observations give the researcher a freedom to choose which data that is worth gathering from the observation. Furthermore, Robson (2011) argues that the observer should strive to reduce their involvement as far as possible in order to reduce the possibility of bias from the observed area. One advantage of observations versus interviews is that the collected data is not dependent on the interviewee's recollection of previous events or personal bias when trying to communicate the answer to the interviewer (Patel and Davidson, 2011). Therefore, observations can advantageously be used in conjunction with interviews.

3.2.3 Test Assembling in the Current Assembly Process

Ulrich and Eppinger (2012) argues that those who directly decides over the design of the product or process must experience the "use environment" in order to take the right decisions regarding the product's design. This is also stated by Bicheno (2004), who claims that according to the TPS, there is a word called Gemba. Gemba means "the place where activities take place", and refers to the fact that data should be collected where the process is located. The test assembling will constitute such an understanding and overview in order to evaluate where the project work should be focused to maximise the outcome.

3.2.4 Data Collection

During the test assembling, several methods to collect data were used. The data was captured in order to analyse the discoveries made at a later stage. Before the test assembling, an evaluation was made to find the most recurring cart types and components because that was where improvements were expected to benefit Flexqube the most.

Collection of Data From Sold Carts

In order to find the most sold carts and components, a data collection was made. The data was partly gathered from the Flexqube website where the latest sold carts are added continuously, but also from the inventory statistics shared by the supply chain manager at Flexqube. The data from the website consisted of the bill of materials (BOM) from the last 200 sold carts and were retrieved manually. The data from the inventory statistics consisted of all parts and carts sold throughout the year. The inventory statistics were then categorised using Excel. This data collection was later used to analyse where an improvement had the largest impact.

Video Recording

Videos are a great tool to capture data for the analysis due to the ability to relive past experiences (Bicheno, 2004). Partly to bring certain events back to memory but also to find new possibilities which might not have been taken into consideration before. According to Baudin (2002), video recording has many advantages over just using a stopwatch, although demanding some more equipment. Baudin (2002) further argues that using video to capture the current state in an assembly improvement concept is "..a powerful analytical tool". The video recording will provide the foundation for the standard work sheets (SWS) which are further described later. Bicheno (2004) argues that for such a purpose as the SWS, video recording is preferred compared to a live scenario since you are able to rewind and play in slow motion.

Notes of Shortcomings

During the visits of the assembly plants in Georgia, USA and Torsby a notebook were kept at close hand at all times. This, in order to capture all small and large shortcomings in the assembly plant during the days we were present. The notes were a great compliment to the video recordings since the notes could contain situations that the camera could not capture and also situations unfolded in the past which co-workers witnessed about.

3.3 Data Analysis

Mertens et al. (2017) define data analysis as a method where optimally all data that may influence the outcome is identified and measured. The collected data has been used to map the current assembly process, find opportunities where to improve the process, find the waste during assembly work and to find components and carts which are over-represented. This since improvements there might have the largest impact on the overall assembly process.

3.3.1 Evaluation to Find the Most Common Parts and Carts

The first part of the evaluation built upon the inventory statistics, obtained from the supply chain manager at Flexqube. By knowing the most common components, attention could be focused on those components during test assembly, observations and interviews. Since they are highly represented in the carts, any inefficient assembly operations containing these components might have a high impact on the overall assembly process. The data extracted were:

- Most common cart types
- Most commonly used parts

The second part of the evaluation used a formula designed in Excel that calculates how large share of the carts that contains a specific component, regardless of the number of parts per cart, and visualises this data in percent. This calculation was used as a cross-reference towards the inventory statistics in order to make sure that not a small quantity of sold carts contained a large number of a specific component. The following information was compiled:

- Most commonly used bolts and nuts
- Most commonly used parts

3.3.2 Mapping of Current Assembly Process

To map the current assembly process and make it easier to analyse, the assembly process, from the inventory to the shipping of carts, was divided into eight sub-processes. A flowchart was made, which according to Damelio (2011) is a graphic illustration of sequences needed to produce a specific output. Other methods used were brainstorming, fishbone diagram and workshops, which are further described below.

Individual Brainstorming

Ulrich and Eppinger (2012) defines brainstorming as an approach where ideas are generated from already known knowledge within the team. The first brainstorming session included only the group members and a blank sheet of paper which was used for every single process stage. All possible pro's and con's that could be encountered were listed.

Workshops

According to Ulrich and Eppinger (2012), a workshop is defined as a group of people with relevant expertise where individual evaluations are performed. Further, Ulrich and Eppinger (2012) argues that a workshop may be used in order to screen opportunities. The topic of the workshop was “evaluation of the assembly process” and the purpose of the workshop was to list all possible pro’s and con’s for each process step. These will constitute as an internal wish and demand list, where all the positive sides of each step are considered a demand for the new concept and the negative aspects are considered wishes, or things to improve.

Fishbone Diagram

A fishbone (or Ishikawa diagram) is used to identify both categories and its underlying causes to a certain problem, often within quality improvement processes (Law, 2016). There are several variants of fishbone diagrams, one of which is named the 5-M method (Mania, 2016). In this project, the fishbone diagram has been used to find all possible causes to why the current assembly process is ineffective and inefficient. The 5-M method has also been extended to a 7-M method in order to adapt the method to the assembly process. The 7-M’s consists of: method, manpower, management, machine, measure, milieu and material.

3.3.3 Value Adding Work Analysis

According to George et al. (2005) a value adding analysis identifies which activities in a work process that adds value to the customer. The first step conducted in analysing the videos was to time different steps of the assembly process. All actions made by assembly personnel were named, timed and later placed in a category. The categories were, “fetch components”, “place components”, “tighten bolts”, “waste” and lastly “other”. The categories were chosen with regard to Boothroyd et al. (2011), who claims that manual assembly is mainly divided into two categories. First, handling, which is described as “acquiring, orienting and moving the parts”. Second is the insertion and fastening, which includes grouping the components together. This was made in order to find out how much of the actual assembly time that was value-adding but also to see the distribution of the above-mentioned categories.

3.3.4 Standard Work Sheets

Ortiz (2006) suggests a method called standard work sheets (SWS) for setting up each workstation, where e.g. work content, sequence time, cycle time, part quantity, part description and tools are listed. This data was used as a guideline in order to compare and analyse the differences in time between the existing assembly process and the new assembly concept.

3.4 Solution Development

In the following section, the methods applied in order to come up with the solution is described. To generate ideas, brainstorming and paper-based mock-ups have mainly been used.

Brainstorming

According to Ulrich and Eppinger (2012), idea generation is a relatively inexpensive and can be done rather quick in comparison to other parts of the development process. The process starts with a selection of needs and targets and ends in a range of concepts from which the team can make a final selection. To generate ideas, several methods exist to support the idea generation. One method used is brainstorming and is described by Ulrich and Eppinger (2012) as an internal search where all ideas come from the team's personal experience and can be performed individually or in a group. According to Milton and Rodgers (2011), brainstorming is a rapid and highly effective method to generate innovative and surprising concept proposals and is best used in a group, but can be used individually as well. The brainstorming was conducted in order to quickly capture quantitative ideas rather than qualitative ideas. The reason for this was, as described by Ulrich and Eppinger (2012), that the more ideas a team generates, the more likely they are to fully explore the different solutions.

3.4.1 Paper-based Physical Mock-ups of the Assembly Layout

In order to generate ideas related to the layout of the assembly process, paper-based physical mock-ups were cut out. This method is suggested by Baudin (2002) who exemplifies visualisations on paper as a method to design assembly processes. The mock-ups were then disposed on a range of different layouts, ranging from u-shaped assembly layouts (Baudin, 2002) to straight assembly lines (Gurevsky et al., 2013). Common for all layouts were the demand for flexibility suggested by Simon Algesten (2018). Boothroyd et al. (2011) refers to this as a "flexible assembly layout", which makes the usage of storage carts more efficient due to its increased proximity.

3.5 Solution Evaluation

The solution evaluation was used as a method in order to reduce the number of ideas generated from the brainstorming. In order to come up with the best solution, Johannesson et al. (2013) suggest a solution evaluation where apparent unfeasible solutions should be eliminated.

3.5.1 Decision Matrices

According to Johannesson et al. (2013), decision matrices are good tools to further eliminate the worst solutions but also to possibly find new solutions that are combinations of already existing solutions. The matrices have been used to analytically screen out the best alternatives and to come up with new solution combinations. The matrices used in this project are further described below.

Concept Combination Matrix

With inspiration from the morphological matrix, a concept combination matrix was created. Instead of combining functions with part solutions, the matrix combined part solutions with each other. This due to the fact that generated ideas already contained total solutions with different part solutions. The matrix was used to cross-fertilise the generated solutions and to make forced connections between existing solutions in order to find new possible solutions.

Elimination Matrix

The elimination matrix is used to screen out all solutions that do not solve the task, fail to meet the demands or are unfeasible (Johannesson et al., 2013). That way, only the most potent solutions can continue into the next phase of the evaluation, and no waste is made evaluating unfeasible solutions.

Concept Screening Matrix

According to Ulrich and Eppinger (2012), the purpose of the concept screening matrix is to narrow down the number of concepts quickly and to improve the concepts. Ayağ (2014) further argues that the Pugh matrix, as it is also commonly called, is a simple and fast matrix which makes it perfect to screen out unfeasible options quickly and early on. However, it does not take into account the importance of each criterion.

Weighting Matrix

Since not all criteria have the same degree of importance for the final solution, a weighting matrix was created. The criteria were evaluated one versus one, whether they were more or less important or if they were equally important. If one were more important then they were assigned one point whereas the other got zero points, if equally important, both were given a half point. Lastly, the points were summarised. This is proposed by Johannesson et al. (2013) as an optional method to use.

Concept Scoring Matrix

The concept scoring matrix, or Kesselring matrix, has been used and is described by Ulrich and Eppinger (2012) as a method to use to better distinguish between the remaining solutions. In the concept scoring matrix, all solutions are graded with respect to the weighted criteria from the weighting matrix. The concepts were graded between one and five on how well they fulfilled the criteria in the matrix.

3.5.2 Evaluation of Assembly Layout

Frequent communication and discussions have been held with Per Augustsson, CTO, Flexqube, in order to evaluate the assembly layout. Requirements that supported the evaluation were e.g. size of the factory, efficiency and flexibility.

3.6 Evaluation of Result

In order to evaluate whether the final concept is an improvement or not, prototyping has been used to compare the new concept with the current assembly process. Ulrich and Eppinger (2012) describes PoC as a prototype to quickly test ideas in order to confirm the functionality of the product. This is also confirmed by Ullman (2010) who describes PoC as a model to develop the functionality of the product and to verify that the customer needs are satisfied. Otto and Wood (2001); Ullman (2010) argues that a PoC does not need to fulfil the products exact properties, but only focus on some key components or sub-systems of the product. Also that it is not important which materials are used only that they are cheap and easy to come by. Baudin (2002) states that computer simulation of assembly concepts are unnecessary unless it is a highly complex assembly line, and that using mock-up assembly equipment is sufficient for testing a new concept. This was also confirmed by Simon Algesten (2018) who argued in favour for simplicity by saying “hold things in the right place” and “fold things in cardboard, be very pragmatic and simple and take advantage of the fact that there is a result - what actually happens”.

4

Current Assembly Process

In order to help the reader to understand the upcoming chapters, this chapter goes through the assembly process as it is today. The chapter explains the assembly guidelines and the current working stations where the actual carts are assembled together. This is followed by the assembly layout which includes the overall layout of the assembly process and its surrounding. Finally, the tool presentation and material presentation are described.

4.1 Assembly Guidelines

When designing the carts for the customers, a 3D-pdf is generated from the CAD software where the cart is designed. The 3D-pdf is used in the assembly process as a guide to assemble the cart. Once several carts of the same type have been built in the assembly, the need for the 3D-pdf is reduced since the assembler learns how to build the cart. An example of a 3D-pdf can be seen in Appendix B.

4.2 Working Stations

In the current assembly process, a separation has been made between "assembly station 1" and "assembly station 2". Station 1 includes the first part of the assembly where the frame is built, including the assembly of e.g. beams, wheel attachment boxes and corner plates (for a tugger cart). For the same cart, station 2 includes attachment of e.g. casters, handlebar attachments and top plates. In Figure 4.1 the two stations are illustrated.

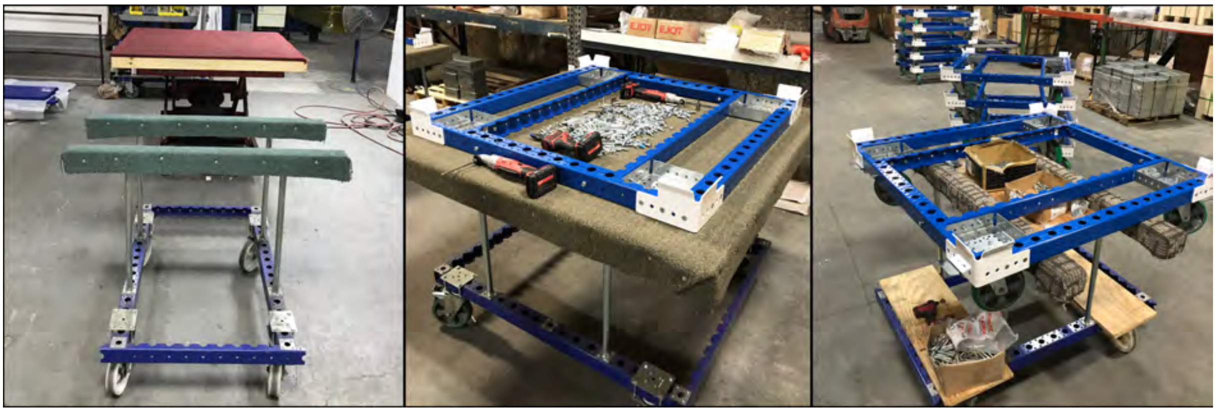


Figure 4.1: From the left: station 1 (red) and 2 (green), station 1 and station 2

4.3 Assembly Layout

The layout of the current assembly process is set-up in a straight line and surrounded by three large shelves appointed in a u-shape, as illustrated in Figure 4.2. The assembly process starts from the left where station 1 is marked and continues through station 2 followed by a preliminary storage of the completed cart in the right corner of the figure.

Several obvious drawbacks could easily be identified with the existing layout. One of the drawbacks was that the u-shaped shelves created a bottleneck when the material was out of supply. The material refill operation demanded all of the assembly equipment to be moved out of the way and stopped for several minutes in order to make space for a forklift to refill the material. No material refill from the back of the shelves was allowed due to safety aspects. Another drawback was the low utilisation of space. For example, instead of having a computer at the actual assembly area, where it would easily fit, the assembler had to walk for about 50 seconds (one way) to be able to get instructions from the 3D-pdf. Also, as soon as the preliminary storage of the carts was full, the assembler had to walk for approximately one minute (one way) to leave the carts in another area. Figure 4.3 demonstrates the assembly process in action.

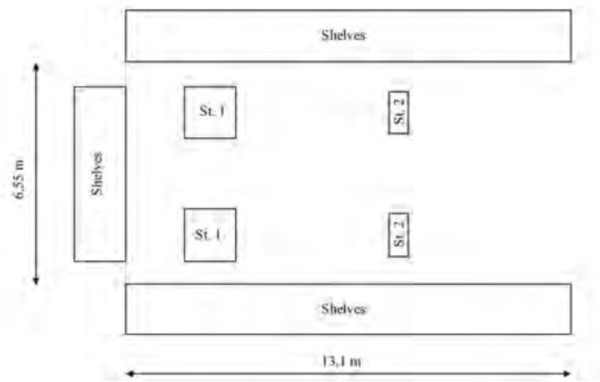


Figure 4.2: 2D-overview of the current assembly layout

Figure 4.3: The current assembly layout in action, picture taken from short shelf

4.4 Tool Presentation

When the working shift ends, all tools are collected and gathered in certain positions in order to facilitate the upcoming shift. However, no guidelines for the tool handling are implemented during the working shift. Instead, the tools are placed wherever the assembly worker is performing the task, meaning that tools can easily be misplaced. This may lead to waste since assemblers occasionally have to search for tools.

4.5 Material Presentation

The current presentation of the material is mainly stacked and placed on the floor on a pallet. This causes unergonomic lifts for the assemblers since heavy components have to be picked from the floor and lifted up to a convenient working height. Examples of how the material is presented today can be seen in Figure 4.4.

(a) Flexbeams™

(b) Wheel attachment boxes

Figure 4.4: A selection of material presentation in the current assembly

4.6 Ergonomics in the Current Assembly

The ergonomics in the current assembly process is generally poor. There is a lot of heavy lifts, poor working angles and bad postures needed during assembly. The heaviest lift is when the completed cart from station 2 has to be lifted down on the floor. This procedure is both heavy and has to be carried through in a bad posture due to the handlebar and towbar being located where they are. Furthermore, there is also assembly operations which have to be made from underneath the frame e.g. Flexplates™ and casters (see Figure 4.5). Lastly, some components have to be held with one hand while inserting the bolt and nut with the other, this can be tiring for the hand but it is also not as productive as being able to use both hands for assembling.

Figure 4.5: Figure illustrating assembling from underneath causing a poor posture while attaching Flexplates™

5

Empirical Research

The following chapter concerns the knowledge gained from real life experiences. These experiences include interviews made with people from the theoretical field, the industry and assembly personnel. Also, study visits to companies that share some of the assembly challenges with Flexqube have been made. Lastly, test assembling of Flexqube's various carts has been performed which has been a big contributor to the understanding of the assembly process. Below, the procedures performed in order to reach these experiences are explained.

5.1 Interviews and Study Visits

In total, eight different persons have been interviewed. These eight persons have been divided into three groups, namely "experts", "industry" and "Flexqube". The first group included three professors from Chalmers. Subjects concerning modularity, product development and production analysis were discussed. Takeaways from these interviews were e.g. various techniques which can be used in order to reach improvements in the assembly process on a more theoretical level, literature recommendations and factors to consider before planning the actual assembly layout.

Next, three people from the manufacturing industry (Volvo trucks, Scania and Modul-system) were interviewed in order to discuss how they use certain techniques and methods and what their experiences were. Takeaways from these interviews were among others how they work to improve the assembly, the importance of a flexible and ergonomic assembly and recommendations for setting up a new assembly concept.

The third group consisted of two interviews which were held with the assembly managers, Jeff and Wesley, at Flexqube's assembly plant in Georgia, USA. The intention of these two interviews was to contribute to a deeper understanding of needs in the current assembly process. The result of these interviews consisted of a lot of information regarding the shortcomings in the current assembly process and also several ideas where and how improvements could be made to facilitate a more streamlined assembly process, further explained later.

During the interviews at Modul-system and Volvo trucks, a guided study visit was also made to their respective assembly lines. The guided study visit made it possible to continuously ask questions regarding the assembly process during the tour. The study visits contributed with knowledge and inspiration of e.g. layout, ergonomics, methods, tool usage and part presentation. Furthermore, due to the fact that Volvo trucks partly use Flexqube's carts for internal logistics, the visit was even more rewarding since feedback from the use of the carts could be obtained.

5.2 Test Assembling

The empirical research phase main part was the test assembling of carts at Flexqube's two assembly plants. Five days were spent at a company named Advanced Metal Components (AMC) in the USA, and two days were spent at Wermlands Tunnplåt AB (WTAB) in Torsby, Sweden. Flexqube has outsourced their assembly to both of these companies and place of assembly are dependent on the geographical location of the end customer. During the visits, a total of seven different carts variants were assembled. Also, video was recorded during the different conducted activities throughout the visits.

5.2.1 Test Assembling in Georgia, USA

During the visit, Flexqube's assembly plant in Swainsboro, GA consisted of two assembly lines, one for lower volumes with higher variation and complexity and one with higher volume and lower variation and complexity. The first day was spent at the high volume line, helping with the assembly of tugger carts and also included a guided tour of the plant. The next day was spent observing different activities in the plant. First observations were made at the low volume line, where the operators assembled another type of tugger cart, and secondly in the inventory where the picking method was observed. The following days were mostly spent on assembling carts, both on the low and high volume line. Additional activities included palletising and wrapping of carts for shipping.

Assembling the carts provided unique knowledge that can not be taught or learned from second-hand sources. The test assembling affected the idea generation and solution development immensely because of the insight gained from the current assembly process. The test assembling contributed further with a deeper understanding of where shortcomings are present in the current process, and these shortcomings were written down as they were discovered. Furthermore, the knowledge gained from the assembly supported the creation of interviews meant for the assembly personnel. A holistic picture of the whole assembly process was gained which facilitated to more qualitative questions for the interviews, which in turn will contribute to a better data collection.

5.2.2 Test Assembling in Torsby, Sweden

The visit to Flexqube's other assembly plant in Torsby was made in order to see the differences from AMC, to get more inspiration where improvements could be made and also to test the assembling of a few more different cart types. The test assembling consisted of five different carts that Flexqube was going to use for exhibitions in Europe during the spring. For example, a shelf cart which represents approximately 20 percent of all sold carts. This visit mostly concentrated on test assembling but minor observations were also made covering e.g. the inventory and assembly layout.

Apart from what was concluded from the test assembling in Georgia, USA, the test assembling in Torsby gave some new experiences. These experiences included assembling of other types of carts, but the visit also confirmed some of the drawbacks in the assembly from the USA, mainly the need for a more ergonomic assembly station.

6

Data Analysis

The following chapter concerns the analysis of the captured data. In this case, the data is not just defined as raw data, but also data in terms of knowledge gained from the experience in the empirical research.

6.1 Identification of Common Carts and Parts

Since Flexqube's carts vary greatly between almost every project and may consist of a wide array of components, an analysis was made in order to find which carts and components that were the most recurring ones. In order to do so, a list of all sold components and carts during the twelve trailing months (TTM) was provided by the supply chain manager.

Carts

A total of 2700 carts were gathered into an Excel document including part number and the name of the carts. The conditional formatting tool was used in order to separate the carts into categories. All tugger carts were identified by using the keywords "tugger", "low rider", "50 x 50", "50x50", "48 x 33", "pallet", "45,7 x 49,6" and "container cart". All shelf carts were identified by using the keyword "shelf". The rest of the carts which were not identified were labelled as "others". The data is presented in Figure 6.1.

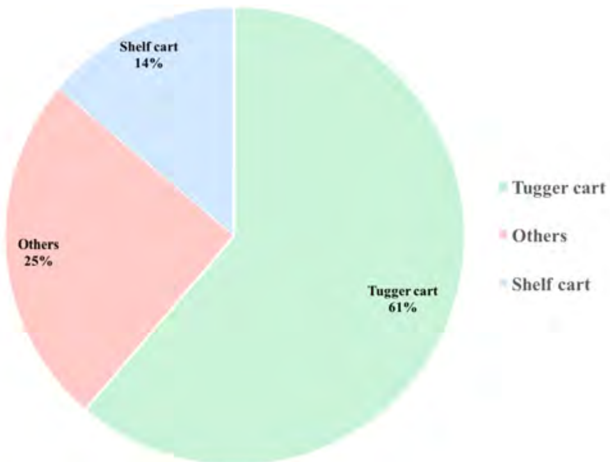


Figure 6.1: Distribution of carts sold during the trailing twelve months

Components

The first data analysis of the components was based on the supply to the customers. The components were ordered based on "used parts" to identify what components that are used to the greatest extent. All screws, bolts and nuts were excluded due to its already known over-representation (confirmed in Figure 6.3). In addition, a screening was made to eliminate components that were used in a smaller quantity. Therefore, this data only contains the 18 most used components. This enabled for a visualisation of the distribution in between the most expended components. The keywords that the formula used to find the components were made so that all variation of one component was calculated, even if it was a different length or material. The distribution of the components was based on both the assembly in Sweden and USA (TTM). The data is illustrated in Figure 6.2. The content of "Other" is presented in Appendix C and the most common Flexbeams™ are presented in Appendix D.

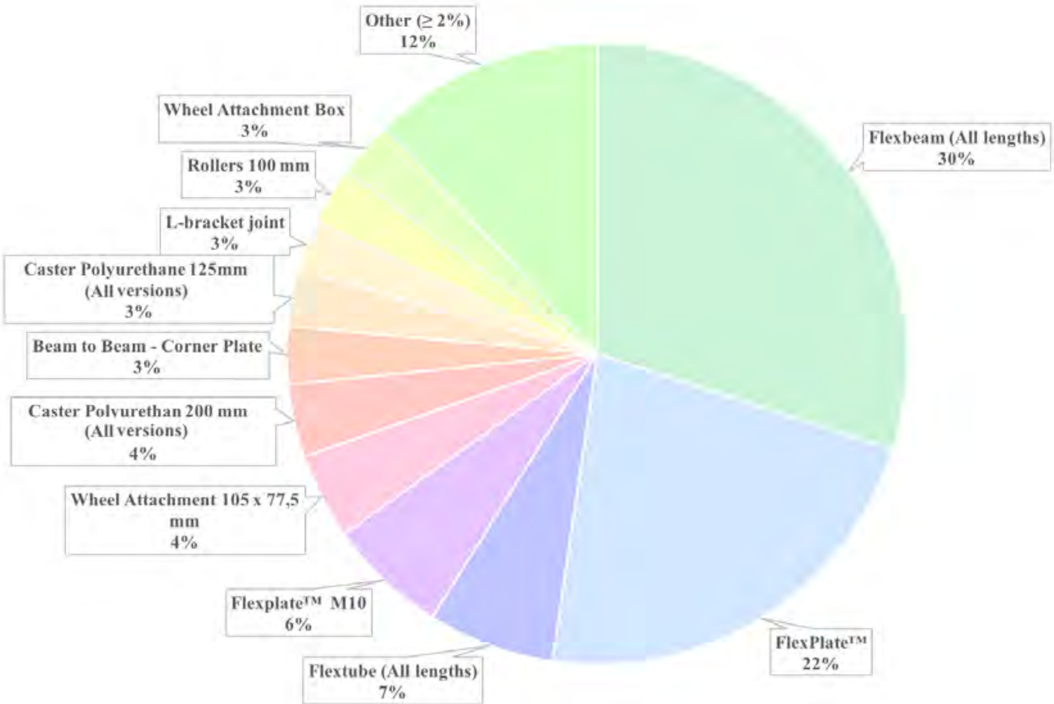


Figure 6.2: Distribution between the 18 most used components (quantity)

The second data analysis of the components included another approach in order to get a different perspective of the analysis. Instead of measuring the expended components in terms of sold quantity, the components were measured based on how many carts they were included in, measured in percent. This was performed by using a formula in Excel which calculated whether a certain component was included in the cart or not. The numbers are presented in Figure 6.3 and additional information regarding the usage of bolts can be found in Appendix E and Appendix F. This data is based on the last 200 sold variants.

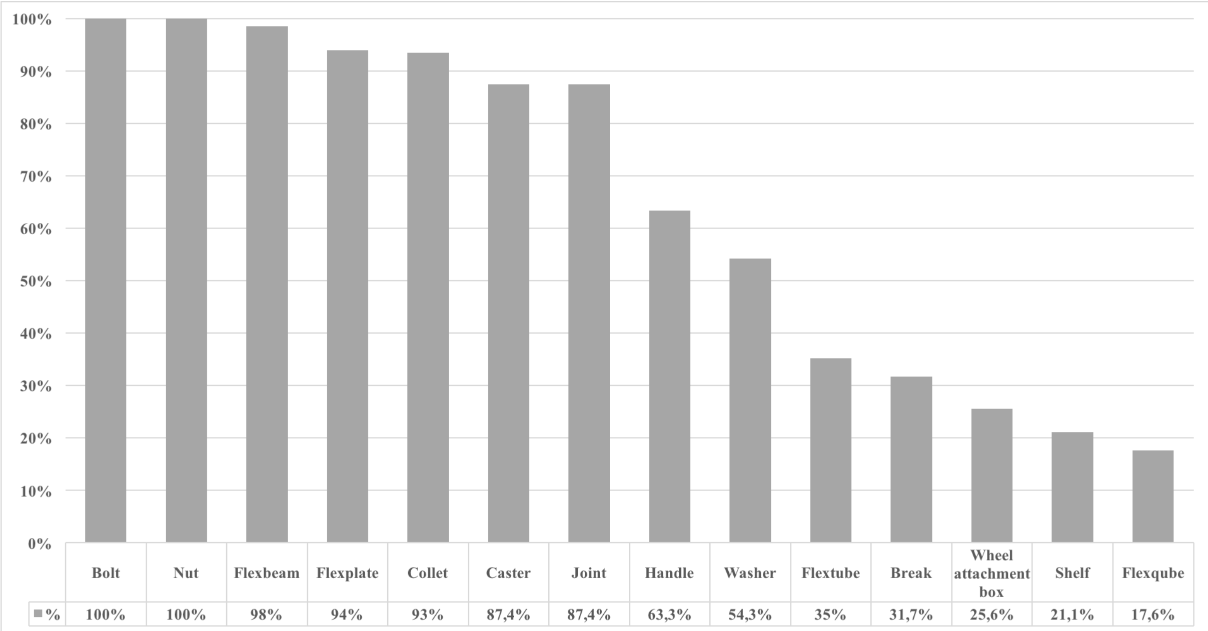


Figure 6.3: Distribution between the most 18 sold components

6.2 Standard Work Sheets

The basis of the SWS was the video files captured during assembly, both in the current assembly process but also with the new improved assembly concept. Because of the carts being almost identical, the work could be divided into the same categories for both of the SWS's made. An analysis was then made using a stopwatch to time the duration of each of the different categories during the recorded video. The sequences from the assembly, the work content and its duration is taken from the test assembling in the USA, before improvements were made, can be seen in Table 6.1. This SWS will later be compared to the SWS for the new assembly concept.

Workstation 1 (before improvements)		
Sequence	**Work Content**	**Duration**
10	Place all corner plates	00:00:23
20	Place all flexbeams	00:01:14
30	Place all wheel attachment boxes	00:00:50
40	Insert all bolts, collets and locking nuts	00:11:01
50	Attach all flexplates	00:05:26
60	Install tow hinge attachment	00:01:24
70	Mount tow hole	00:01:28
80	Fasten all locking nuts on bolts	00:05:01
90	Move to station 2	00:00:15
		00:27:02

Workstation 2 (before improvements)		
Sequence	**Work Content**	**Duration**
100	Attach all casters	00:09:06
110	Attach tow bar	00:03:05
120	Mount floor brake	00:02:12
130	Mount handlebar attachment	00:01:36
140	Mount handlebar attachment with floor brake	00:01:41
150	Mount handlebar	00:03:11
160	Place top plate	00:00:48
170	Mount top plate	00:05:58
		00:27:37

	Total time	**00:54:39**

Table 6.1: Standard worksheet before the improvements

6.3 Value Adding Work Analysis

As with the SWS, the value adding work analysis was conducted with the help of the recorded videos. The analysis was conducted on the current process in the USA. All activities made by the assembly workers were documented and timed. The analysis was made during a whole assembly cycle and is based on one occasion. The documented activities were then put in different categories regarding of where they belonged. The categories were: "fetch components", "place components", "tightening of bolts", "waste" and "other", further described below.

- *Fetch components* - included the movement from the time the previous action ended to picking up the material and moving it back to the cart assembly. If the component were located at an unreasonably long walk from the assembler, the walking part was regarded as waste.

- *Place components* - started right after the "fetch component" was completed and included the steps to align the components making them ready for the bolts and also inserting the bolts and nuts making them ready for tightening. If the insertion of bolts demanded walking to fetch bolts, this was regarded as waste.

- *Tighten bolts* - included grabbing the necessary tools, aligning them for tightening and finally tightening the bolt.

- *Waste* - if the tools were misplaced and had to be brought back, this was regarded as waste. Examples of actions put in the "waste" category were walking, removal of packaging material from components, not being able to insert bolts due to faulty components, double work, moving things obstructing current action, searching for tools or components and using the wrong tool.

- *Other* - actions such as charging batteries for the power tools, preparing work area were deemed semi value adding and was placed in the "other" category.

The timed actions were categorised and put into a diagram providing a perspicuous view, see Figure 6.4. The total time for assembly of one tugger cart can be seen in Table 6.2, and will later in this report be compared to the time of the new assembly concept. The data in Figure 6.4 is based on one assembly sequence.

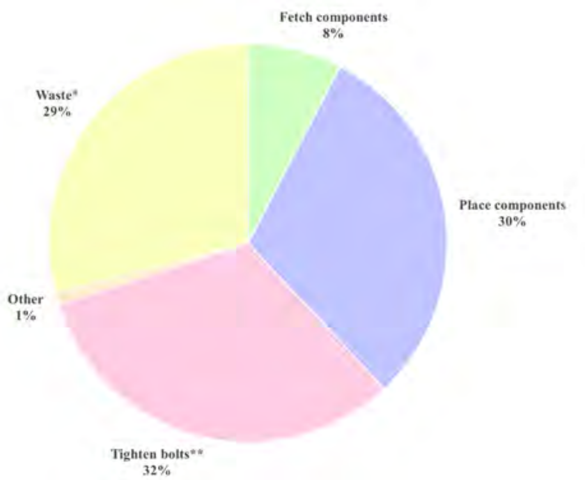


Figure 6.4: Pie chart illustrating the distribution between work content

* *Transportation, double work, defective components etc.*
** *Of which 10 percentage points are related to self-tapping screws*

	Station 1	Station 2	Total
Total work time	00:27:54	00:35:55	01:03:49
Value adding work	00:21:02	00:22:56	00:43:58
Value adding + Other	75%	64%	71%
Waste	25%	36%	29%

Table 6.2: Table showing the distribution of working time

6.4 Analysis of Current Assembly Process

As mentioned in the method chapter, the current assembly process was divided into eight stages according to personal experience from the test assembly in the USA. The eight stages can be seen in Figure 6.6.

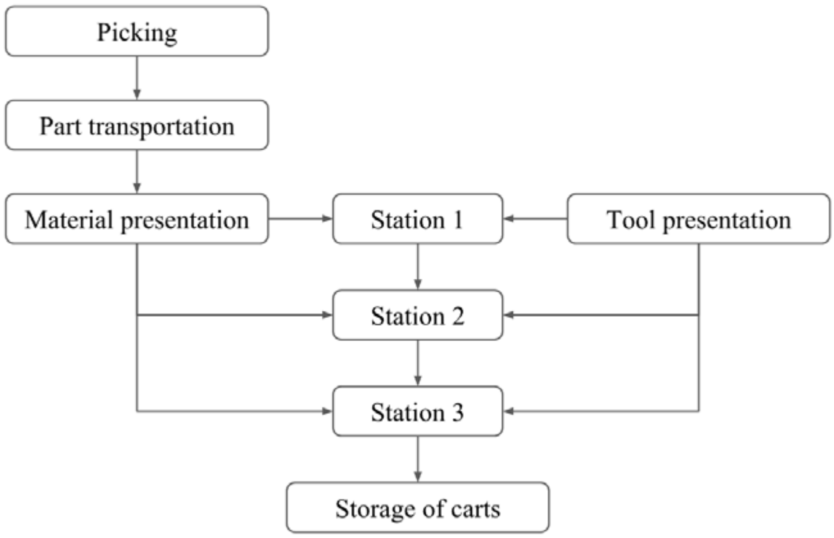


Figure 6.6: Assembly process divided in to eight stages

The splitting of the assembly process into sub-stages was done in order to favour the brainstorming of drawbacks in the process.

6.4.1 Pro's and Con's of Current Assembly Process

In order to identify the positive and negative aspects of the current assembly process, a list of all the pro's and con's was compiled. All critical aspects of today's assembly concept were identified by separating the assembly process into subsystems, as illustrated in Figure 6.6. A list for each subsystem was made were all possible pro's and con's were listed. The list can be found in Appendix G. The identification of pro's and con's was completed individually, based on personal experiences from the test assembling and from input made by the assembly workers.

6.4.2 Identification of the Eight Wastes

To identify waste in the current assembly process the waste was split up in eight categories, commonly abbreviated as TIMWOODS which includes: transport, inventory, motion, waiting, over-production, over-processing, defects and skills. Notes from the test assembling and personal experience contributed with the data. The complete list can be seen in Appendix H.

6.4.3 Fishbone Diagram

As mentioned in the method chapter, the 7-M method was used in the fishbone diagram. There, everything that could impact why the assembly process is inefficient and ineffective was listed under the categories method, manpower, management, machine, measure, milieu and material. The fishbone diagram is based on the impressions from the study visits during the empirical study. These impressions have been obtained from both observing and own experience. The root cause of the fishbone diagram is defined as ”the assembly process is ineffective and inefficient”. A simplification of ”effective” is ”to do the right things” (Wheelwright, 1992) while the corresponding definition of ”efficient” is ”doing things the right way” (Roghaniana et al., 2012). Each category of the fishbone diagram is further described below and a Figure of the fishbone diagram in a whole can be seen in Figure 6.7.

1. *Method* - the working procedure of the assemblers and their environment.
2. *Manpower* - factors related to the actual workers.
3. *Management* - content which are based on the leadership of the assembly.
4. *Machine* - the usage and faults related to machines or tools.
5. *Measure* - quantitative and qualitative aspects of the assembly.
6. *Mileu* - the surrounding and its impact on the assembly
7. *Material* - the components and its affection on the assembly.

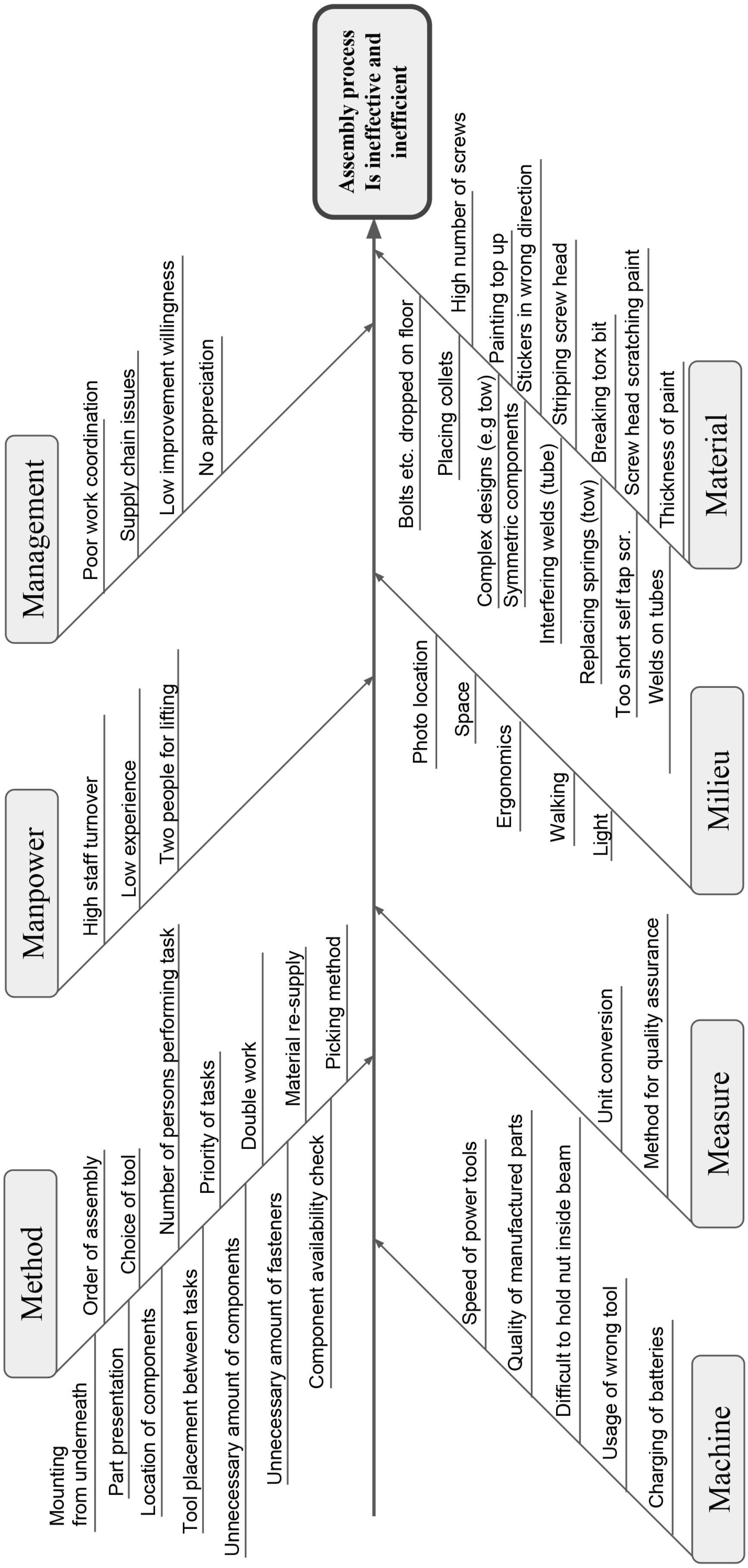


Figure 6.7: Fishbone diagram based on current assembly process

7

Solution Development

The following chapter describes the procedure performed to reach the final solution. The final solution consist of a "system level assembly concept", which in turn includes the "assembly station concept" (see Figure 7.1). Apart from the assembly station concept, the system level assembly concept also includes delivery of components, transfer of completed carts from the assembly area, material presentation and tool presentation.

In the upcoming sections, the processes applied in order to come up with the system level assembly concept and the assembly station concept are further described. The description includes an explanation of how these concepts have been developed to meet the requirements.

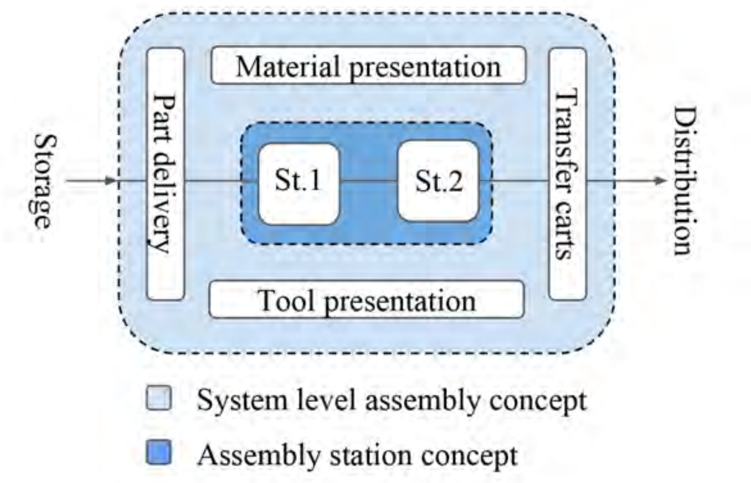


Figure 7.1: Visualisation of the solution development

7.1 System Level Assembly Concept

The following section describes the procedures performed in order to come up with the system level assembly concept.

7.1.1 Workshop

As an attempt to increase the quantity of the pro's and con's of the existing assembly process, a workshop with employees at Flexqube was set up. The workshop included four persons from the company, namely the CTO, the sales manager, the design manager and the supply chain manager. This in order to get ideas and inputs from throughout the value chain. The purpose of this workshop was to benefit from the overall experience that already exists within the company. Due to limited time and despite efforts made to govern the workshop, it was difficult to prevent the participants from discussing more solution related content, which resulted in a poor outcome.

7.1.2 Paper-based Mock-ups

In order to come up with a lot of different proposals on the assembly layout, paper-based mock-ups were created (see Appendix I). The paper-based mock-ups enabled for a quick shuffle of the assembly layout which facilitated the discussions. Assembly layouts that deemed to have potential were further developed using Google slides. These layouts were then further discussed, evaluated and combined in order to come up with the final layout.

7.1.3 Brainstorming

As a complement to the layout, a brainstorming session was performed which focused on the surroundings of the assembly area. This included alternative ways to store components, how to present tools for the assembler, how to store finalised carts etc. In combination with the final layout concept, part of these ideas constitute the final concept of the system level assembly concept.

7.2 Assembly Station Concept

The following chapter describes the development of assembly station 1 and assembly station 2.

7.2.1 Brainstorming

At first, an individual brainstorming session was performed. This was performed on a blank piece of paper where all emerged ideas were sketched. Secondly, a brainstorming session was performed in a group, including both group members. The brainstorming included ideas for the whole assembly station concept, including the development of both station 1 and station 2, or a combination of both.

8

Solution Evaluation

In order to analytically narrow down the concepts, a range of decision matrices was used. The evaluation has been made based on a selection of criteria which have its origin in the previously developed list of pro's and con's, which was based on the current assembly process. Throughout the project, the goal has been to keep all pro's on the list whilst eliminating as many con's as possible. Below follow the matrices and the workflow used.

8.1 Concept Combination Matrix

The brainstorming session brought a range of concepts, of which a certain amount was eliminated due to duplicates as a result of the individual brainstorming session. As the brainstorming session was completed, a concept combination matrix was created in order to combine the concepts. All concepts were named a letter or a number in order to get an overview of how they could be combined. A matrix was created as seen in Figure 8.1, where all possible combinations were evaluated. If the combination of the concepts was considered to be plausible and hold a certain degree of potential, a plus sign was given. If not, a minus was given. A total of 105 potential concepts were generated (including the 14 already known illustrated in the diagonal line). Out of these, 41 were assigned a plus sign meaning that they were considered to have potential. Even though some concepts could have been eliminated prior to the combination matrix, they were decided to remain. This made the concept combination matrix more time consuming but this decision was motivated by the reasoning that a very abstract solution may become realisable if combined with another.

	A	B	C	D	1	2	4	5	6	7	8	9	11	12
A	+	-	-	+	+	-	-	-	+	-	-	-	-	-
B		+	-	+	+	-	-	-	-	-	+	-	+	+
C			+	+	-	-	-	+	-	-	-	-	+	-
D				+	-	-	-	+	-	+	-	-	+	-
1					+	-	-	+	+	+	-	-	-	-
2						+	-	-	-	-	-	-	+	+
4							+	+	-	-	-	+	+	-
5								+	+	-	-	-	-	+
6									+	-	+	+	+	-
7										+	-	-	-	-
8											+	-	-	-
9												+	-	-
11													+	-
12														+

Table 8.1: The concept combination matrix used to combine generated concepts

8.2 Elimination Matrix

After the concept combination matrix, a total of 41 concepts were compiled. In order to reduce the number of concepts, an elimination matrix was used. The elimination matrix made 41 concepts into 6 by challenging each concept for certain criteria, as can be seen in Appendix J. Due to the high number of concepts generated from the concept combination matrix, of which a lot were quite abstract, the elimination of the concepts went all the way from 41 to 6.

8.2.1 Concepts Remaining After Initial Elimination

The remaining six concepts are illustrated in Figure 8.1. In the upcoming subsection, each concept is further described in detail.

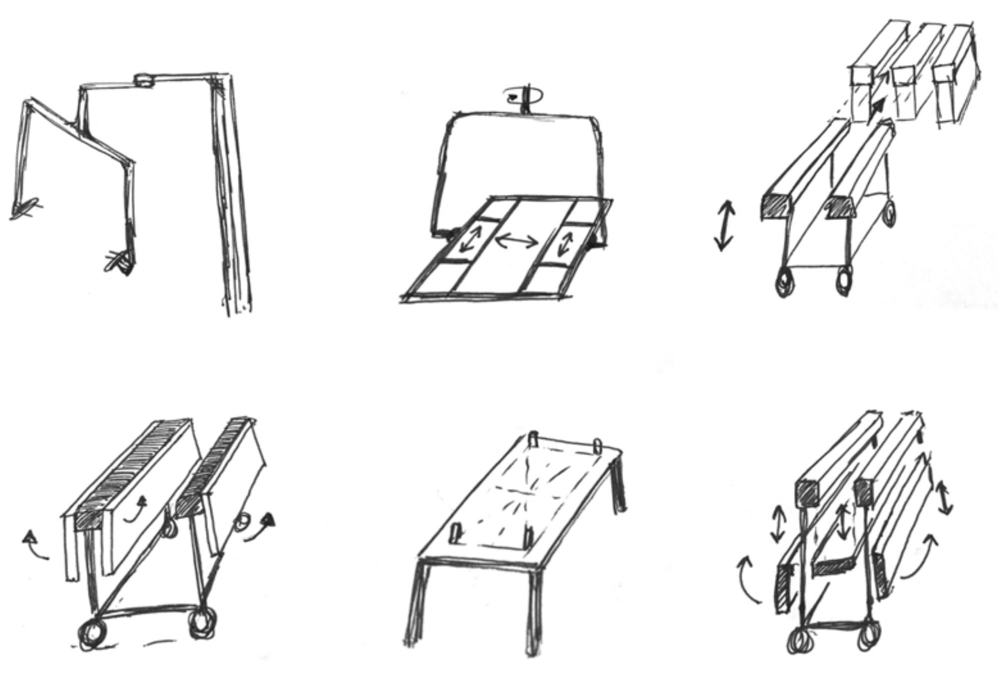


Figure 8.1: Sketches of the six remaining concepts. From the top left corner: Jib Crane, Flexrail, Dock & Lift, Flaps, Piston Lift and Drop-flap

Concept 2, "Jib Crane"

The jib crane uses a crane or a beam in the ceiling to allow a hanging jig. The jig connects to the frame from two sides and then lifts the frame from station 1. The rest of the assembly is done while the frame is hanging. The frame can be rotated around the axis where it is connected to the jig as well as adjusted in height inside the jig.

Concept 9, "Flexrail"

Flexrail is an adaptable table consisting of adjustable support rails. As seen in Figure 8.1, the two long rails can move horizontally while the four shorter rails can move vertically so that they support the assembly of the frame. Due to the thin profile of the support rails, the assembly operations performed at station two can be performed in the same station. If the frame is secured, it can also be rotated and later lowered to the ground. Before production starts, the rails are set to fit that specific cart, meaning there is no need to move the support rails more than at the beginning of a new cart variant.

Concept 6-11, "Dock & Lift"

This concept consists of a flat assembly table to facilitate the assembly of the frame. Two parts of the assembly area is a movable cart. When the frame is completed, the cart is slightly lifted which allows the cart to be rolled away and can be used as station 2.

Concept 5, "Flaps"

Flaps is a transformable assembly station. At first, it acts as station 1 providing a full table top. When the frame has been assembled, three flaps are folded through the use of hinges which allow the assembly operations normally occurring at station 2 to be performed without the need for a lift. Although eliminated in the concept screening matrix, inspiration was taken into the final assembly concept where two flaps are being used on station 1 to facilitate the docking of the rotating assembly station.

Concept BD, "Piston Lift"

The piston lift has a flat table top to support the assembly of the frame. When the frame is complete, four pistons raise the frame from the table top to facilitate the mounting of remaining components which requires access to the bottom of the frame.

Concept 5-6, "Drop-Flap"

The drop flap is similar to concept 5, "flaps" but has the ability to lower the cart to the ground.

8.3 Criteria for the Concept Screening Matrices

The different criteria used for evaluation of the concepts in the matrices were chosen in order to reach the best possible solution. The criteria and why they are important can be read below.

Efficiency

Increased efficiency is a key goal of this project and is a measurement of how well resources can be transformed into products. The efficiency criteria were split up into sub-categories to make it easier to grade concepts and to give each concept a fair assessment. The subcategories are explained more in detail below and were as follows:

1. *Flexibility between various carts* - how well the concept could support shifting cart types in production
2. *Avoid switching between stations* - how well the concept eliminates the need for the assembler to move around while assembling
3. *Avoid transport* - how well the concept minimised movement between assembly operations
4. *Ease of manoeuvring* - how easy the concept was to manoeuvre between assembly operations
5. *Adjustable height* - if the concept could lower the cart to the ground to eliminate the need for the assembler to wait for a co-worker to help with the lift

Ergonomics

Ergonomics is important not only to protect the workers from physical or mental illness but to increase productivity since tired assemblers are not as productive. Furthermore, the hidden assembly could have an impact on quality due to the lack of sight from the worker. Ergonomics were further split into four different subcriteria.

1. *Accessibility* - how well the assembler could access the different assembly operations
2. *Ability to avoid heavy lifts* - how well the concept eliminates the heavy lifts which are present in the current assembly process
3. *Ability to avoid reaching* - the concept's ability to eliminate reaching movements of the worker
4. *Ability to avoid poor angles* - how well the concept could eliminate assembly from poor angles

Prevent damage to components

The last criteria the concepts were assessed against were the damage prevention criteria. This criterion assesses the risk of components being damaged during assembly due to the assembly concept. Since damaged components have to be replaced, this criteria can impact both the productivity of carts and the costs for Flexqube.

8.4 Concept Screening Matrix

The concept screening matrix (or Pugh matrix) has been used to rank concepts based on if they were better or worse than the reference concept in terms of fulfilling the above criteria. The matrix was performed twice, first with one of the concepts chosen randomly as the reference (Table 8.2), and secondly with the concept which performed best in the first round as reference (Table 8.3). Concepts were given "one", "minus one" or "zero" whether if they were expected to perform better, worse or equally good. In the first round, the lowest scoring concept was eliminated (red in the figure). During the second round, two concepts performed equally poor in the concept screening matrix and ended up with minus two points and were therefore eliminated so that only three concepts remained for the concept scoring matrix.

	BD	2	5	5-6	9	6-11
Selection Criteria	Piston Lift	Jib Crane	Flaps	The DropFlap	FlexRail	Dock & Lift
Efficiency						
Flexibility between various carts		0	0	0	0	+
Avoid switching between stations	R	-	0	0	+	-
Avoid transport	E	+	0	0	+	0
Ease of maneuvering	F	+	0	0	+	0
Adjustable height, lower to floor	E	+	0	0	+	0
Time to transform station	R	+	+	0	+	+
	E					
Ergonomics	N					
Accessability	C	+	0	0	+	+
Ability avoid heavy lifts	E	0	0	0	0	0
Ability to avoid reaching		+	+	+	+	0
Ability to avoid poor angles		+	0	0	+	0
Prevent Damage						
Risk to scratch components		0	0	0	-	0
Total +	0	7	2	1	8	3
Total 0	0	3	9	10	2	7
Total -	0	1	0	0	1	1
Net score		6	2	1	7	2

Table 8.2: The first concept screening matrix

	BD	2	5	9	6-11
Selection Criteria	Piston Lift	Jib Crane	Flaps	FlexRail	Dock & Lift
Efficiency					
Flexibility between various carts	0	0	0		+
Avoid switching between stations	0	-	0	R	-
Avoid transport	-	0	-	E	-
Ease of maneuvering	-	0	-	F	-
Adjustable height, lower to floor	+	+	+	E	+
				R	
Ergonomics				E	
Accessability	-	0	0	N	0
Ability avoid heavy lifts	0	0	-	C	0
Ability to avoid reaching	0	0	0	E	0
Ability to avoid poor angles	-	0	-		-
Prevent Damage					
Risk to scratch components	+	0	+		+
Total +	2	1	2	0	3
Total 0	4	8	4	0	3
Total -	4	1	4	0	4
Net score	-2	0	-2	0	-1

Table 8.3: The second concept screening matrix

8.5 Weighting Matrix

	Efficiency	Ergonomics	Safety	Prevent damage	Feasability	Ease of lower to floor	SUM
Efficiency		0,5	0,5	0	0	1	2
Ergonomics	0,5		0,5	0,5	0	0,5	2
Safety	0,5	0,5		1	0	1	3
Prevent damage	1	0,5	0		0	1	2,5
Feasability	1	1	1	1		1	5
Ease of lower to floor	0	0,5	0	0	0		0,5
							15

Table 8.4: The weighting matrix

A weighting matrix was created to grade the importance of each criterion. For the weighting matrix, the base of the criteria was the same as in the concept screening although, the criteria were not as detailed. This decision was made due to a very time-consuming process for the concept screening matrix, which was considered to be too detailed and therefore very hard to evaluate. Instead, "efficiency", "ergonomics" and "safety" were evaluated as a whole since its subcategories were eliminated. The criteria "prevent damage", "feasibility" and "ease of lowering to floor" were added since these criteria were crucial if the concept would become reality, after discussions with the supervisor at Flexqube.

8.6 Concept Scoring Matrix

In the concept scoring matrix, the concepts were graded between one and five on how well they fulfilled the criteria in the matrix. The criteria consisted of the six most important factors retrieved from the weighting matrix. The grading was done subjectively and analytically on how well a concept was expected to fulfil the specific criteria based on personal experiences from the empirical research in the assembly plants. This grade was then multiplied by the weight of that specific criteria and given a weighted score. The values were then summarised and compared to the optimal value as a percentage of the whole. Concept 2, "Jib Crane", scored best out of the three concepts, and was also the concept chosen for further development. The matrix can be seen in Figure 8.5.

		Concept					
Selection Criteria	Weight	2: Jib Crane		9: FlexRail		6-11: Dock&Lift	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Efficiency	2	4	8	4,5	9	3	6
Ergonomics	2	5	10	5	10	3	6
Safety	3	3	9	3	9	4	12
Prevent damage	2,5	4	10	2,5	6,25	4	10
Feasability	5	4,5	22,5	2,5	12,5	4	20
Ease of lower to floor	0,5	5	2,5	3	1,5	3	1,5
Total	SUM:	62		48,25		55,5	
	Optimal:	75		75		75	
	Percentage:	82,7%		64,3%		74,0%	

Table 8.5: The concept scoring matrix

8.7 Choosing the Final Concept

Due to additional demands from Flexqube which emerged during the solution evaluation phase, the winning concept 2 was slightly changed during discussions with the supervisor from Flexqube. Concept 2 was an assembly station hanging from the ceiling. Due to the demand of a more flexible overall assembly concept, a non-hanging assembly station was desired from Flexqube. Due to this fact, the assembly station was slightly changed, from hanging to supported by wheels. Other than hanging, the new assembly station had the same key features as before. The change of concept 2 to a non-hanging concept was not a totally new concept since that type of concept had earlier been eliminated with the only reason that it was too similar to concept 2. This can be seen in Appendix J, where concept 4 checks all boxes except "uniqueness". The earlier eliminated concept 4 can be seen in Figure 8.2.

In order to facilitate the docking of the rotation dollies to carts with varying widths at station 1, inspiration was taken from an already eliminated concept, namely concept Flaps, see Figure 8.1. The sides of station 1 were fitted with hinges in order for the table top to be folded down after the assembly of the frame. This in order for the rotation dollies to access the frame and to ease the docking.

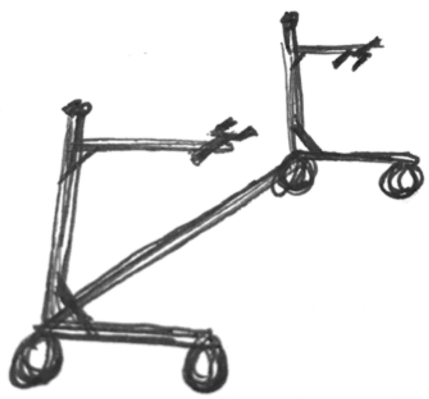


Figure 8.2: The "Fork on wheels" concept which was eliminated due to lack of uniqueness

9

Prototyping

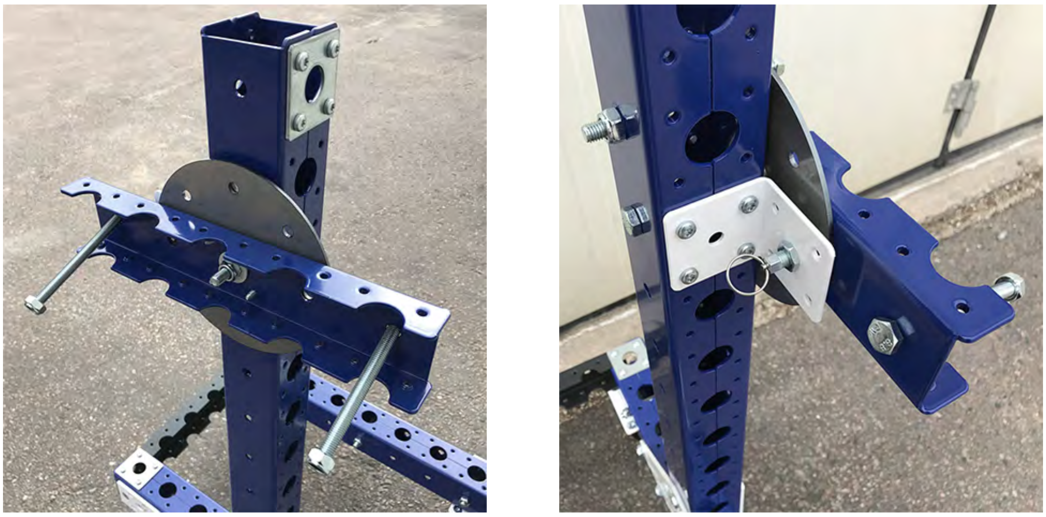
The prototyping focused on testing the new assembly concept, with the elimination of the waste found in the current assembly process, and also to test the new rotatable assembly station generated from the concept development. The testing was carried out with provisional, although comparable with real, mock-ups for material and tool presentation along the assembly line. As mentioned in the methods chapter, PoC is a quick and cheap way to verify that the functionality of a product works satisfactorily.

9.1 Rotation Dollies

The prototyping started with the development of the rotation dolly, which is the concept for station 2. The focus was to design an easy prototype with Flexqube's own components which could facilitate the rotation of the cart during assembly. A sketch of the rotation dolly was handed to Flexqube's design engineer to create a CAD drawing and a BOM, so that all components needed could be ordered. At arrival in Torsby for the PoC, the two rotation dollies were assembled (See Figure 9.1).

Figure 9.1: Overview of the rotation dolly

The two dollies have the ability to dock into the frame from each side and move it away from assembly station 1 without a lift. This is enabled through a submersion of station 1, which transfers the lifting force from the station 1 to station 2. The rotation dollies enable the cart to be rotated 360 degrees and locked in eight different positions to enable easier and quicker assembly. The method for attaching the frame in the dollies has in the prototype been made very basic. The mechanism to rotate, lock and attach the frame can be seen in Figure 9.2. The rotation dollies are a simplification made solely to test the concept in the PoC. When station 2 is later described in this report, that represents a further developed rotation dolly made for use in the assembly line.



(a) Cart attachment

(b) Rotation locker

Figure 9.2: Detailed picture of the prototype

9.2 Proof of Concept

The PoC was conducted at Flexqube's assembly plant in Torsby, during two days. The PoC was conducted with a tugger cart near identical to the cart which was assembled and analysed in the USA. The assembly layout was set up as lifelike as possible using an assembly table as station one, and the newly developed rotation dolly as station two. Material was presented on carts next to the two stations. Tools were hung on the assembly station itself and nuts and bolts were available in fixed bins on the respective station. The assembly process, which was also video recorded, were conducted during one continuous cycle to further simulate life-like settings. The completed cart hanging in the rotation dollies can be seen in Figure 9.3, also, note the mock-up bins for fasteners.

Figure 9.3: The completed cart in the rotation dollies

The new concept made use of a new type of collet, developed by Flexqube. The collet is placed between Flexbeams^{TM} to facilitate the alignment of the beams and to allow high torque tightening of the bolts. The new collet is made of plastic instead of steel and enables beams to be attached together, not falling when placed upright so that the insertion of bolts is made easier which helps a lot for the overall assemblability.

The process of the new concept started with the fetching and placement of corner plates, beams and wheel attachment boxes to station 1. After the components where placed, the plastic collets where inserted which made it possible to place the beams upright, to facilitate the insertion of bolts. Next, the bolts were inserted and nuts fitted, one side of the cart at a time. Step three involved the tightening of bolts, first the hex heads, then the allen heads, one side at a time. After fastening was done, the rotation dollies were attached to the frame. In Figure 9.4, the assembly process is visualised in six steps.

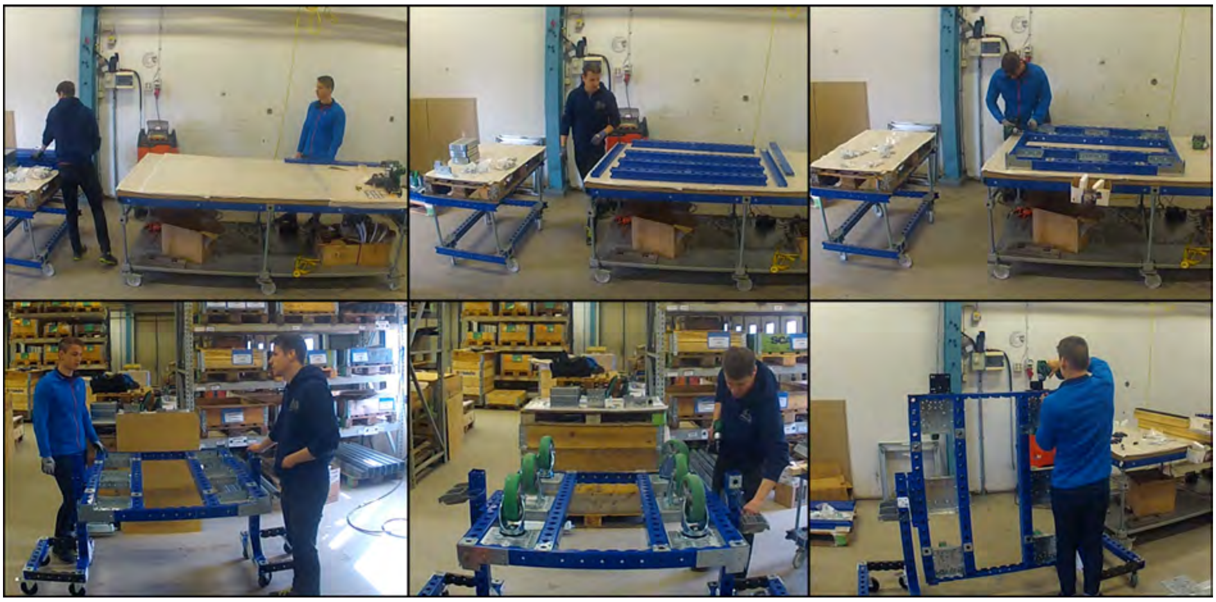


Figure 9.4: Six steps showing the assembly concept

The first step when the cart was attached to to the rotation dollies was to rotate the cart 180 degrees to facilitate the assembly of casters and flexplates, which attach to the bottom of the cart, visualisation of the rotation can be seen in Figure 9.5. First, the casters were placed on top of the rotated cart, then all bolts and nuts were inserted and finally tightened. The same procedure was used for the flexplates. Because of the cart being rotated, both the casters and flexplates could be placed on the frame without the need to hold them in place or bend down to see from underneath. For the next step, the frame was rotated 90 degrees, so that the front of the cart was pointing towards the floor. This in order to mount the tow hole without the need to hold the component with one hand. For the remaining components, the same procedure was used until completion of the cart: rotation of the cart to facilitate placement, insertion of bolts and fitting of nuts and lastly tightening with an impact wrench.

Apart from the above description of the PoC, a new dedicated assembly station for the towbar was tested with mockup assembly equipment. A towbar is illustrated in Figure 9.6, and is used to connect carts when used in cart trains. The assembly station used a vice to hold the towbar while the other components were added, which made it possible to add components to the towbar without the need to hold the towbar itself. Also, since it was elevated from the table top, there was no need to turn the towbar upside down in order to reach the components that were supposed to be attached underneath.

Figure 9.5: Figure demonstrating the rotation of the cart

Figure 9.6: Figure showing an assembled towbar

9.3 Evaluation of the Proof of Concept

As mentioned before, SWS was used in order to document the activities and their duration during assembly. After the PoC was completed, a SWS was performed based on the video recording made during the PoC. The SWS showed an improvement in duration for several assembly operations. The SWS can be seen in Figure 9.1.

Workstation 1 (after improvements)		
Sequence	**Work Content**	**Duration**
10	Place all flexbeams	00:00:53
20	Place all wheel attachment boxes	00:00:34
30	Place all corner plates	00:00:30
40	Insert all collets	00:01:06
50	Insert all bolts and locking nuts	00:08:24
60	Fasten all locking nuts on bolts	00:04:35
70	Move to station 2	00:00:30
		00:16:32

Workstation 2 (after improvements)		
Sequence	**Work Content**	**Duration**
80	Attach all flexplates	00:01:28
90	Attach all casters	00:06:36
100	Lock wheels on rotation dolly	00:00:21
110	Mount tow hole	00:01:05
120	Install tow hinge attachment	00:01:08
130	Mount handlebar attachment	00:01:28
140	Attach tow bar	00:01:48
150	Mount handlebar attachment with floor brake	00:01:05
160	Mount floor brake	00:02:10
170	Mount handlebar	00:01:45
180	Place top plate	00:00:48
190	Mount top plate	00:05:58
		00:25:40

	Total time	**00:42:12**

Table 9.1: Standard worksheet after the improvements

The new assembly concept was perceived as smooth and efficient during the PoC. The waste was minimised and the flow when assembling was improved. The use of the new assembly station 2, the rotation dollies, was also perceived as an improvement, not least from an ergonomic perspective. The components no longer had to be held with one hand while trying to insert the bolts, and components could be mounted from a standing position without the need to mount from underneath the cart.

The dedicated assembly station for the towbar felt like it made the assembling faster and it enabled the assembler to work with both of his hands, not being forced to hold the towbar while attaching components. This was good from both an ergonomic point of view, as well as from a productivity point of view.

During the PoC, the assembly workers and the project leader for Flexqube at WTAB gave their view of the new assembly station. Åsa Engström, the project leader, expressed her satisfaction over the improved ergonomics, the removal of heavy lifting, the ability to rotate and the bins & tool holders attached to the assembly station. The assembly workers expressed consent and agreed that it would indeed remediate some of the drawbacks in the current assembly process. Åsa concluded by saying:

> *"We really hope here on WTAB that the rotatable assembly station will be realised, because we are more than happy to see a bunch of these in our assembly process"*

10

Results

This chapter describes the final solution of this project, including the system level assembly concept and its flows, and also the assembly stations and their carts for material presentation.

10.1 System Level Assembly Concept Layout

A new layout of the assembly has been developed which almost exclusively consists of equipment built with Flexqube's own products. The layout is fully flexible since all parts of the assembly are based on wheels, meaning that the assembly overview presented in Figure 10.1 and Figure 10.2 is just one example of how the assembly could be set up. The approximate length and width of the assembly layout is 25 meters and 11 meters respectively, including the AGV highway.

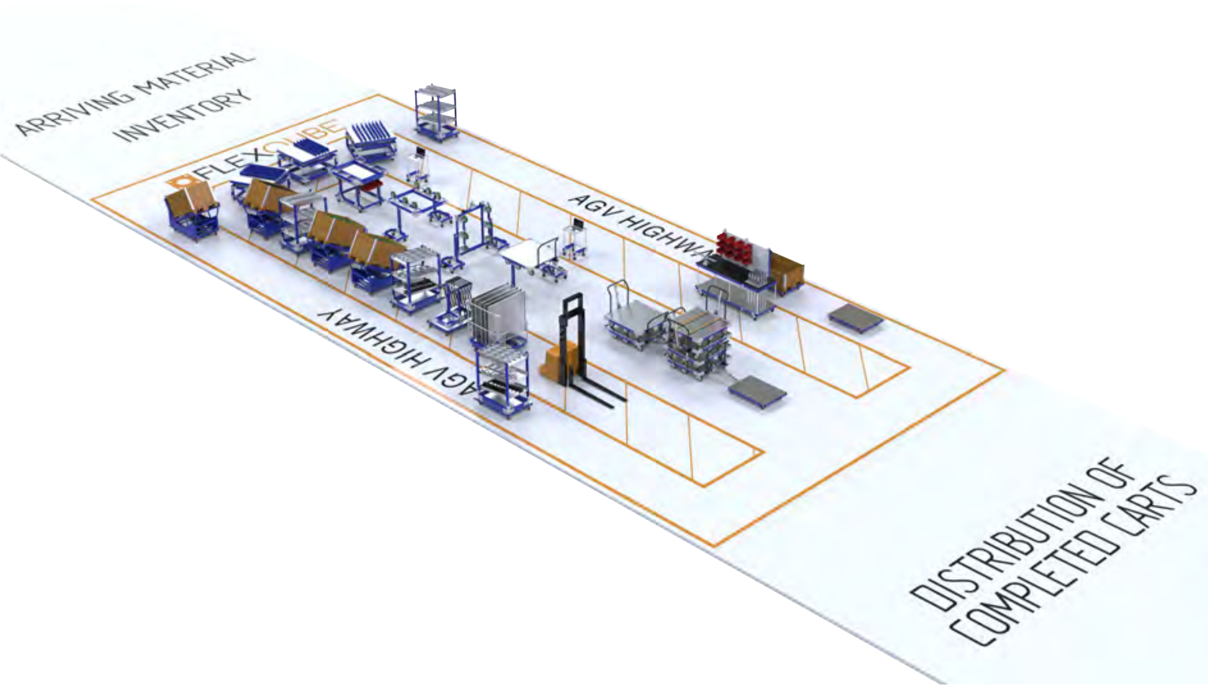


Figure 10.1: 3D overview of the assembly (left angle)

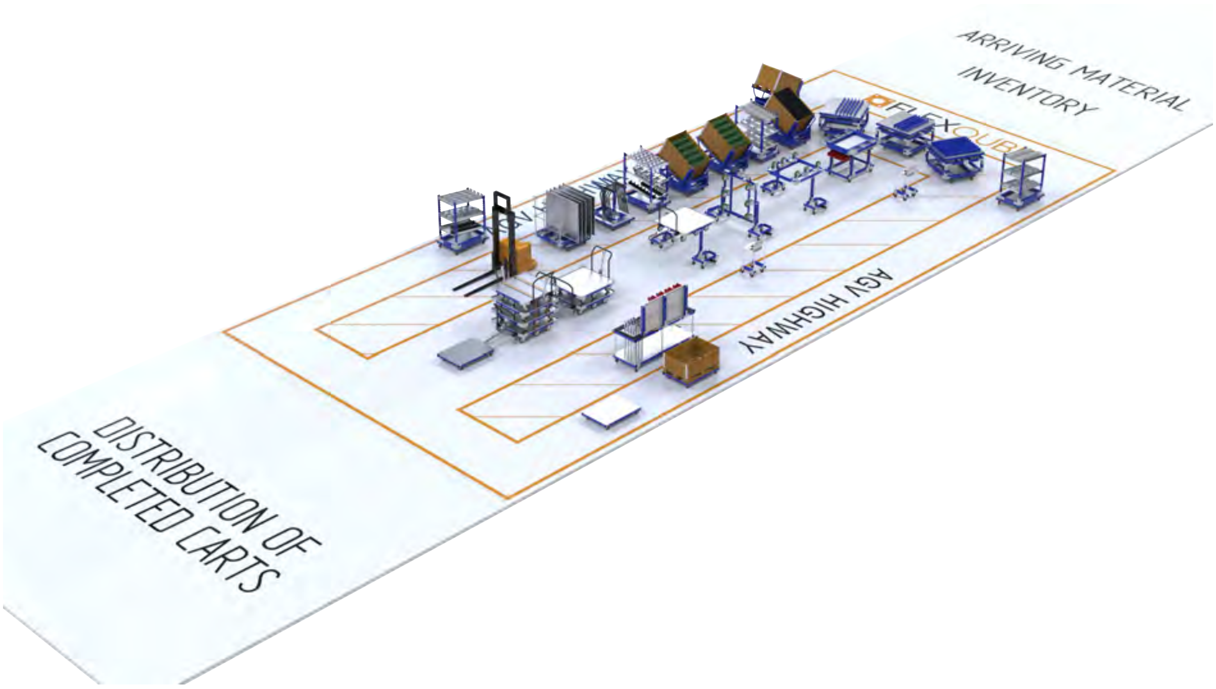


Figure 10.2: 3D overview of the assembly (right angle)

The 3D overview is also complemented with a 2D overview, see Figure 10.3. In this layout, the assembly area is configured for the same type of tugger cart which was assembled during the PoC. Dependent on factors such as cart variant, takt time and manpower, the assembly layout can be adapted to various circumstances. As can be seen in Figure 10.3, the system level concept has a straight material flow throughout the factory. The raw material is delivered in one end of the factory, and in the other end of the factory, finished carts are distributed.

As can be seen in the 2D layout in Figure 10.3, the assembly line is supplied with material from the autonomous material supply carts, which are based on top of automated guided vehicles (AGVs). Autonomous AGVs are currently being developed by Flexqube as part of their industry 4.0 project and has been demonstrated during fairs this year. When the material is out of supply, the material supply carts are exchanged for new ones from the AGV highway. The computers with the 3D-pdf drawing are located close to the assembly stations and are also mounted on wheels so that the computers can be brought close to the assembly station if there is uncertainty about the assembling. The "cart" symbol represents finalised carts and carts that are currently being assembled. The stacker is used to lower the finished cart from station 2 and stacked on the AGV train, which will transfer the carts for wrapping. Since the stacker stacks the carts directly in the assembly and the AGV delivers the completed stack, there is a reduced need for forklifts and manpower to be used for distribution of carts. The workflow in the assembly concept layout follows the same workflow as in the conducted PoC described in the previous chapter.

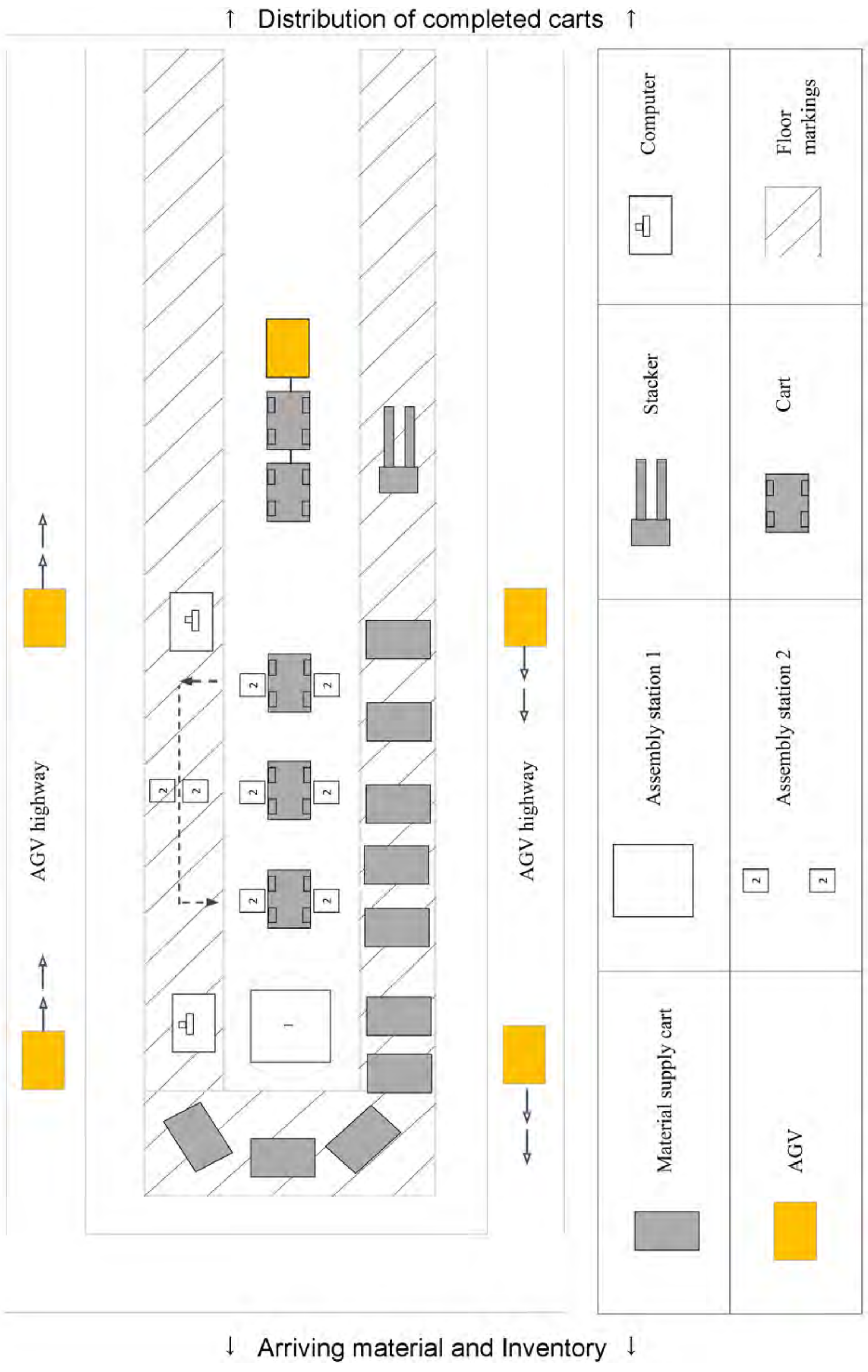


Figure 10.3: 2D-layout of the system level assembly concept

10.1.1 Assembly Station 1

Station 1 is the first step in the assembly, where the frame of the cart is built. It has a fully rotatable tabletop in order to eliminate the need to walk around the assembly table when the four sides of the frame are assembled. Two sides of the table have bins for all needed fasteners attached underneath to facilitate fetching. This also makes it possible to have two assemblers working in tandem on the frame, from two sides, if takt time is changed. Because of the flexibility of the stations, more instances of station 1 can be added to further balance the assembly line if takt time is changed. The other two sides of station 1 have flaps which fold down to enable the docking of station 2. Station 1 also has a submersible function which makes it possible to lower the table in order to transfer the load of the frame to station 2, which then can be moved away. Assembly station 1 and its surrounding material carts can be seen in Figure 10.4.

Figure 10.4: Rendering of the area surrounding assembly station 1

10.1.2 Assembly Station 2

Station 2 has the same functionality as the rotation dollies described in the PoC but needs more development to be fully operational on an assembly line. It should have a fast and easy to use apparatus to secure the frame, bins for fasteners, holders for tools and a minimised footprint. Several instances of station 2 can be used dependent on e.g what kind of cart that is being built, takt time and manpower (see Figure 10.5). Station 2 is moved down the assembly line as the assembly proceeds and is therefore always close to the components that are being assembled. When the cart is completed, the stacker is used to detach the cart from station 2 and to stack the cart behind the AGV. In Figure 10.6, the AGV and the stacked carts are visualised. When station 2 has detached its completed cart, it is moved backwards in the assembly process and is again connected to a newly built frame from station 1.

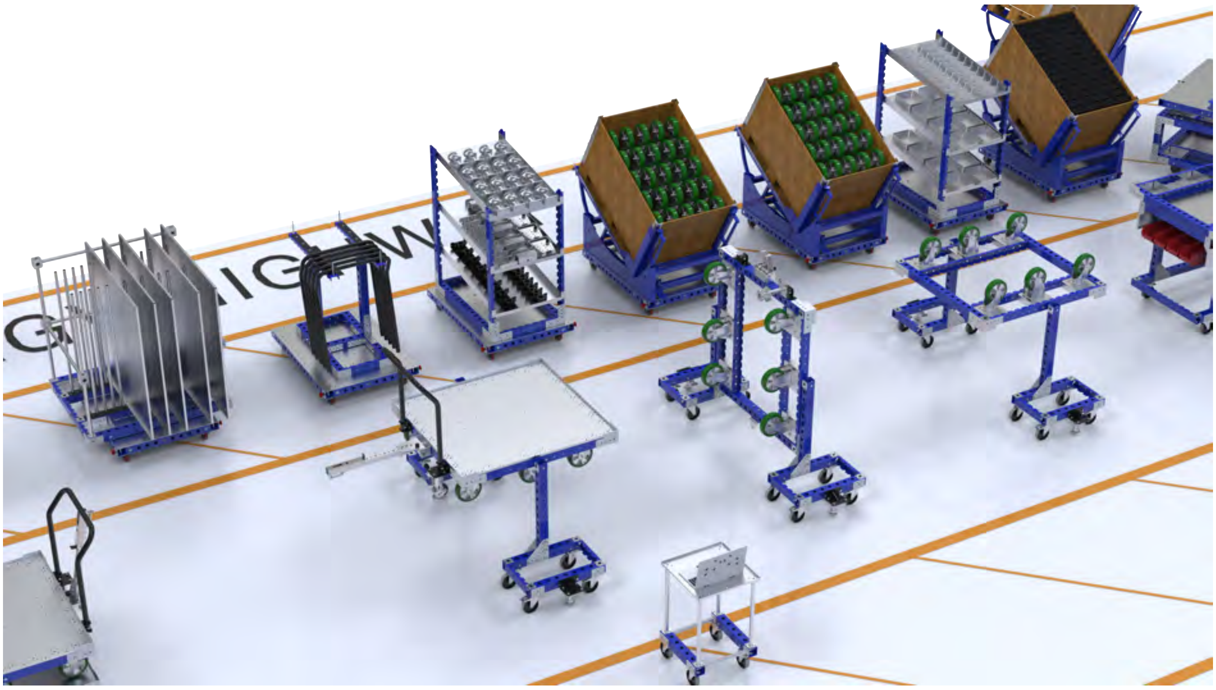


Figure 10.5: Rendering of the area surrounding assembly station 2

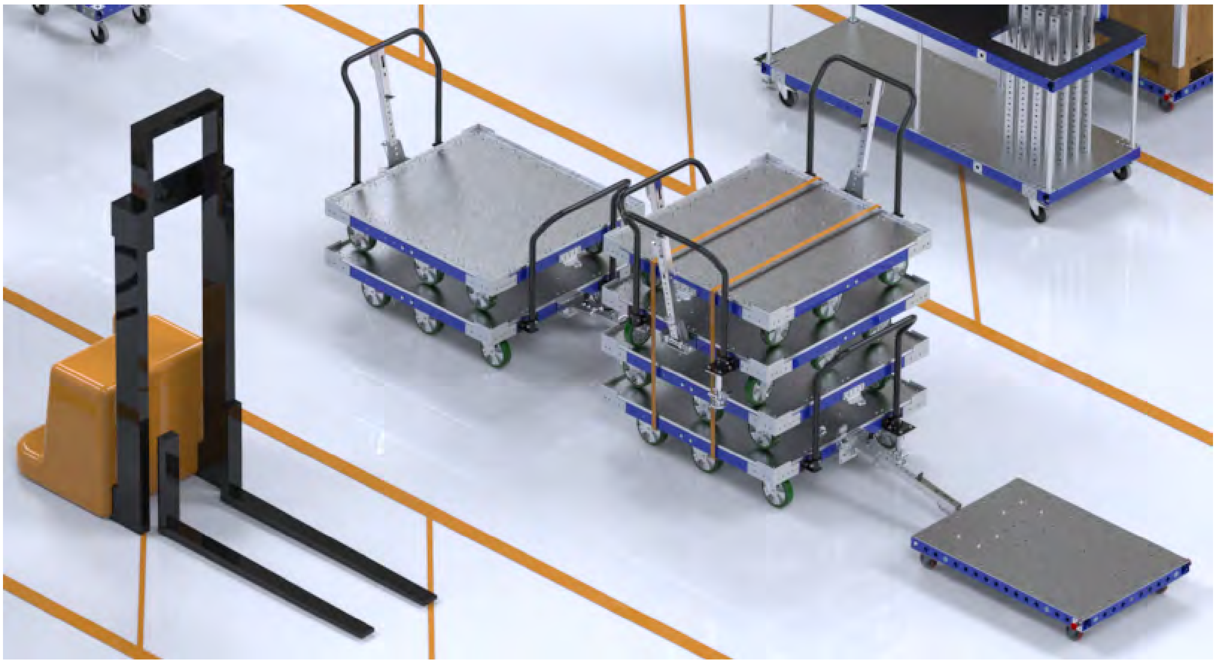


Figure 10.6: Rendering of the stacked carts behind the AGV

10.1.3 Material and Tool Presentation

The following section describes the different carts for components used in the assembly. All of the carts are Flexqube's own carts and has been found on their website. The different carts used can be seen in Figure 10.4 and Figure 10.5.

- The carts being used to supply station 1 with beams has been equipped with a rotatable table top, which is turned 180 degrees when half of the beams have been fetched. This to facilitate easier picking for the assembler and to prevent unergonomic reaching. Therefore, the longest side of the beam should at all times be oriented towards the assembler.

- Low volume components, such as floor brakes and handlebar attachments, has been put on shelf carts and is thereby easy to pick and identify. The shelf carts have angled shelves which makes use of gravity to feed the assembler with components as close as possible.

- High volume components arriving in tall pallets, such as casters and collets, has been put into tiltable carts. This eliminates the need for kitting and facilitates the fetching since the components are always close to the operator even though the component starts to run out.

- The handlebars are hung one by one on a dedicated cart which provides both paint protection and easy fetching.

- The cart used for storage of the top plates has been made so that the plates are placed vertically which benefits the extraction of top plates from the cart. Earlier, the top plates were simply put on a pallet on the floor.

- All fasteners are attached directly to the assembly stations in separate bins which facilitates both identification and fetching.

10.1.4 Dedicated Towbar Assembly Station

Based on the DFA theory, it was noticed that the towbar is built from a wide range of components. In order to facilitate the assembly of the towbar, a working station which is dedicated for the assembly process of the towbar has been developed (see Figure 10.7 and 10.8). This working station has wheels, providing full flexibility in order to match with the other parts of the assembly. The shadow board is equipped with plastic bins as storage for all the small components needed for the towbar. Larger components such as the rectangular tube used for the towbar are stored in proximity and positioned in a vertical orientation due to ergonomic aspects. A vice with a ball joint is mounted on top of the cart where the rectangular tube can be clamped. This enables rotation in all directions of the rectangular tube, which facilitates assembly of the remaining components. The dedicated assembly station for the towbar will most likely make the assembly process more efficient and improve the ergonomics.

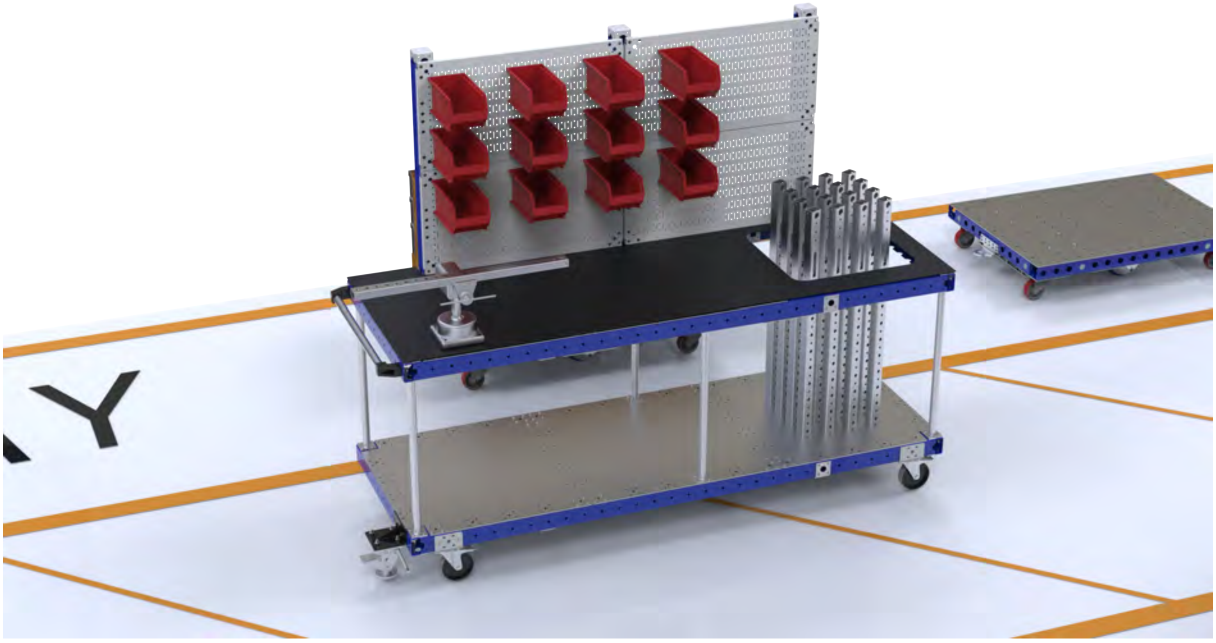


Figure 10.7: The dedicated towbar assembly station

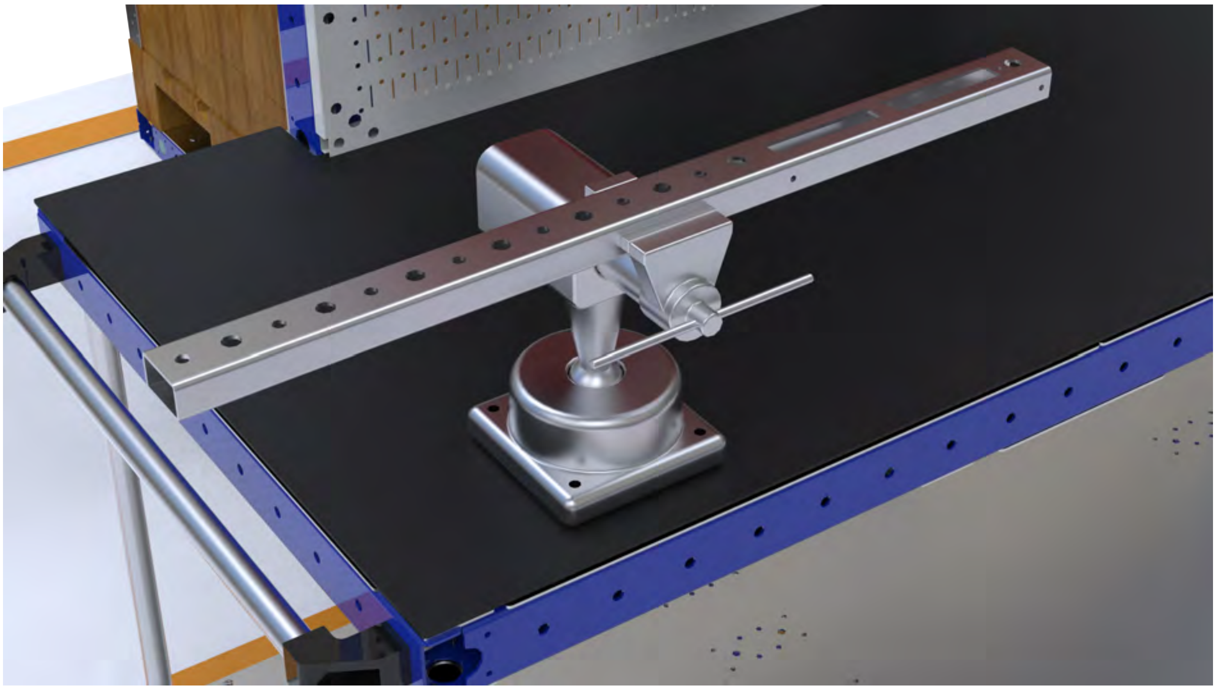


Figure 10.8: A close up of the ball joint vice

10.2 Comparison of the Standard Work Sheets

The result that has been achieved from the SWS covers each working sequence in an isolated manner, meaning that only the working sequences that are present in both SWS are compared. This means that actions considered as waste which was made in between each working sequence are not considered. Therefore, the result presented below are likely to be in the lower interval of the time save. The time save for each working sequence is illustrated in Table 10.1. The total time saved as well as the time saves for each workstation is presented in Table 10.2.

Work Content	Time save	Time save
Place all flexbeams	28.38%	00:00:21
Place all wheel attachment boxes	32.00%	00:00:16
Place all corner plates	-30.43%	-(00:00:07)
Insert all bolts, collets and locking nuts	13.77%	00:01:31
Fasten all locking nuts on bolts	8.64%	00:00:26
Move to station 2	-100.00%	-(00:00:15)
Attach all flexplates	73.01%	00:03:58
Attach all casters	27.47%	00:02:30
Lock wheels on rotation dolly	-	-
Mount tow hole	26.14%	00:00:23
Install tow hinge attachment	19.05%	00:00:16
Mount handlebar attachment	8.33%	00:00:08
Attach tow bar	41.62%	00:01:17
Mount handlebar attachment with floor brake	35.64%	00:00:36
Mount floor brake	1.52%	00:00:02
Mount handlebar	45.03%	00:01:26
Place top plate	0.00%	-
Mount top plate	0.00%	-

Table 10.1: SWS including time save for each working sequence

Station	Before improvement	After improvement	Time save	Time save
Workstation 1	00:27:02	00:16:32	00:10:30	38.84%
Workstation 2	00:27:37	00:25:40	00:01:57	7.06%
Total	00:54:39	00:42:12	00:12:27	22.78%

Table 10.2: SWS including total time save and time save from each working station

10.3 Comparison With the Value Adding Work Analysis

If a comparison is made with the total assembly time recorded during the test assembly in the USA, an even greater improvement can be seen. This, due to the waste elimination made in the new assembly concept, compared to the current. This can not be seen in the SWS which only compares working sequences present in both assembly processes. Comparison to the assembly time found in the value-adding work analysis can be seen in Table 10.3.

Station	Before improvement	After improvement	Time save	Time save
Workstation 1	00:27:54	00:16:32	00:11:22	40.74%
Workstation 2	00:35:55	00:25:40	00:10:15	28.54%
Total	01:03:49	00:42:12	00:21:37	33.87%

Table 10.3: Time saved compared with the value adding work analysis

10.4 Additional Time Save Contributors

Some aspects of the assembly process have been left outside the previously presented time comparison due to difficulties of making a fair measurement. The fact that these aspects are left outside argues for an even better result than what is presented earlier. Some of these factors were mentioned earlier in chapter 4 and each factor is further explained below.

Fork Lift Interruption

The current assembly process is frequently interrupted due to material refill by using a forklift. These interruptions will be eliminated with the new concept since the AGVs are controlling the material refill from outside the assembly area without affecting the assembly workers.

Proximity to Assembly Instructions

In the previous assembly concept, the assembly workers had to walk for about one minute (one way) to get instructions from the 3D-pdf in order to assemble the cart. This is no longer needed since several computers can be placed next to the assembly stations.

Dedicated Assembly Station for Towbar

In the time comparison, no considerations are made concerning the assembling of the actual towbar itself. A working station which is dedicated for a more effective assembling of the towbar has been developed which most likely will improve the assembly time due to its proximity to components and the ergonomic ability of manoeuvring.

Transportation of Assembled Carts

In the current assembly process, the finalised carts are preliminarily stored in the assembly area. When this area is full, each cart is manually transported one by one to the wrapping area where it is later stacked four by four (for tugger carts) with a forklift. The transportation time to the wrapping area is more than one minute (one way) which average over two minutes extra for each cart. In the new assembly, the carts are immediately stacked four by four, if it is a tugger cart, with the stacker in order to prepare for the transportation performed by the AGV. This enables for the assembly workers to use their time for value adding work instead of stacking the carts one by one with a forklift, which was a very time-consuming process. This was confirmed by the assembly manager who argued that “palletising is the most time-consuming part of the process”.

11

Discussion

The following chapter will discuss the result of this thesis. Discussions concern whether the outcome was as expected, the advantages and disadvantages compared to the previous assembly concept and a critical discussion where the procedure of the project will be challenged. In addition, potential shortcomings within the thesis will be brought up. Below follow discussions regarding whether the aim and goals of this thesis has been accomplished.

"Identify and describe the shortcomings in the current assembly process"
Due to several test assembling opportunities, and the video recording made during these, numerous shortcomings in the current assembly process has been identified. The shortcomings have been identified with the help of tools such as "Eight waste's" and the "7-M method" which have earlier been described.

"Shorten the assembly time of a chosen reference cart with at least 25 percent"
The total assembly time was lowered with 34 percent with the new assembly concept compared to the assembly time during the test assembly in the USA. The comparison made with SWS, which isolates just the identical assembly operations, show an improvement of 23 percent. As mentioned before, the SWS does not take all of the identified waste into account which is why the goal to reach at least 25 percent shortened assembly time is considered to be met. However, it must be mentioned that the new collets have been used during the PoC which is part of the time reduction. On the other hand, as mentioned earlier, additional time contributors such as the elimination of the forklift interruption, the proximity to assembly instructions, a dedicated assembly station for the towbar and a more efficient way of transporting the carts for wrapping are factors that benefit the new concept but have not been considered in the time comparison.

"Develop a flexible assembly concept which is insensitive for variation in carts, assembly location and takt time"
The developed assembly concept has a high grade of flexibility. All assembly stations and pallets with components are equipped with wheels, meaning that they easily can be moved and modified to fit different cart variants, demands and locations. The assembly concept also provides flexibility regarding balancing of assembly operations and number of assembly stations to suit different takt times.

”Demonstrate a proof of concept of the improved assembly concept in order to measure if improvements has been made”
A PoC was completed, utilising the improved assembly concept with minimised waste and the developed rotatable assembly station. The PoC showed large improvements regarding the assembly time of the measured tugger cart and also in perceived ergonomics.

”Improve the overall ergonomics in the assembly and eliminate assembly operations with high risk of musculoskeletal disorders”
The PoC showed that the improvements made to the overall concept and especially the rotatable assembly station had a great impact on the ergonomics during assembly. The vicinity to the components, the possibility to mount all components from above instead of underneath and the ability to always be able to use both hands for assembling, all contributed to an overall improvement in ergonomics. Although, the largest improvement to the assembly process is the elimination of the lifting of carts, from the assembly table down on the floor. From experiences during the test assembling, and also input from assembly workers, this activity is the heaviest and most probable source for acquiring MSDs during assembly work.

The theoretical study gave a good foundation of knowledge and has been valuable throughout the project. Furthermore, it contributed with knowledge of what to look for during the empiric research. The empiric research was perhaps the most important part of this thesis, where the test assembling and observations in Flexqube’s assembly plants has been an invaluable experience and source of inspiration. Due to the notes taken, the video recorded and information from Flexqube, a solid compilation of data facilitated the idea generation to cover the whole assembly process and to pinpoint where improvements made the biggest impact. The decision matrices gave, partly, an unbiased screening of the generated ideas and made sure unfeasible solutions were eliminated. The PoC which challenged our assembly concept, was performed in a good phase at the end of the project and proved, black on white, that the improvements gave a more efficient assembly process.

Due to the available space and layout of Flexqube’s current assembly plants, the concept as a whole might not be applicable at these locations. Although, most of the measures can be implemented on their own to the current assembly process.

The presented assembly concept makes use of autonomous AGVs, which are still under development. The implementation of the autonomous AGVs will further improve the productivity of Flexqube’s assembly, since they eliminate the need for a lot of transportation which currently has to be made by assembly personnel.

The development of the rotation dollies into a proper station 2 might be crucial in order for the assembly workers to make use of its benefits. If the attachment during docking, the rotation functionality and the overall usability is not easy enough, there might be a risk that the assembly workers does not use the new equipment.

One thing that could have been made different was to eliminate unfeasible ideas before using the concept combination matrix. Using unfeasible solutions in a combination matrix made the elimination matrix larger and more time consuming. If eliminated before the combination matrix, the overall flow could have been improved. However, as mentioned earlier, a range of concepts were brought into the concept combination matrix due to the reasoning that a very abstract solution may become realisable if combined with another. In hindsight, these abstract solutions could have been eliminated earlier.

During solution development, time was spent developing the concepts on a very detailed level. For example, investigating what kind of bearings that could support the load, stress calculation on beams or which kind of lifting system that could meet our demands. After discussions with the supervisor at Flexqube, he explained that this kind of deep analysis would not contribute with value for Flexqube. What would give value, was a concept on a system level, and if proven to work efficiently, the details can then be investigated after the PoC. This detail level thinking was time consuming and without the concept proven to be more efficient it would not give Flexqube significant value. We agreed upon this and made it an important lesson.

The duration between the meetings with the supervisor at Flexqube was occasionally a bit too long. Due to much travelling in line of work of our supervisor and holidays, meetings between us and the supervisor during the most communication demanding phase, idea generation and solution development, was too infrequent. This caused our vision and the supervisor's vision to deviate. If more frequent meetings would have been held, deviation between our visions could have been aligned at an earlier stage which would have saved time.

Another aspect worth discussing is the validity of the video which Figure 6.4 and Table 6.1 are based on. This data is based on only one operation, meaning that the distribution between the categories may vary between various assembly cycles. However, based on our experience the interpretation is that this data was representative for the reference cart used in this thesis since the same assembly cycle was performed without any significant deviation when the camera was not filming.

12

Conclusions

A concept has been developed which would save at least 23 percent of the assembly time for Flexqube even though it is likely that even larger saves can be achieved. This builds upon the concept presented earlier in this report, including the usage of AGVs. However, a lot of time saves can be achieved solely through removing the faults identified in the current assembly process.

From the analysis of the current assembly process, a lot of shortcomings has been identified and documented. Many of which are remedied from the results of this thesis work. One conclusion that can be drawn is that there is a lot of potential for improvements and if Flexqube wants to reduce their cost, investments in the assembly process are definitely one way to increase the profitability in the long term.

The outcome of this thesis work is a highly flexible assembly concept with improved productivity and ergonomics. Most of the improvements made in the system level concept can be implemented on their own, although the full gain in productivity might not be reached. Due to the use of mainly Flexqube's own components and carts, the investment should be relatively low.

A lot of the improvements made are ergonomic improvements, not least in station 2. These are hard to measure, but from our experience during the PoC, the elimination of the heavy lifts and the rotatable assembly station will benefit the assembly workers greatly. This will not only affect the assemblers physical health but will also benefit the productivity and might reduce the large turnover on staff. Having assembly workers that are experienced increases the quality and reduces time spent on educating new personnel.

No practical recommendation has been made for the tool presentation. This decision was made since this thesis has been performed on a concept level, meaning that the final design is not yet fully determined. When the concept has passed further development, including the detailed design phase, a recommendation is to define designated positions for each tool. If possible, the recommendation is to store tools at the working station where the tool is intended to be used to minimise unnecessary transportation.

13

Recommendations for Future Work

This chapter concludes this report and provides recommendations for future work. Although the goals are considered to be reached, some further development of the assembly concept is needed.

DFA and Reduction of Screws and Bolts

Although left out of this master's thesis report, DFA was studied during the literature study. During the mapping of the current assembly process, thoughts were made regarding the use of DFA on specific sub-assemblies or components in Flexqube's carts. One possible candidate to have its components reduced is the towbar, which consists of a wide array of different components for a rather simple function.

Another candidate would be the number of screws and bolts used in the overall designs. Even though the bolts allow for flexibility in the design, they also increase the assembly time. Certain design changes could be made to some components. For example, a pin or similar would allow the use of less bolts which could further reduce the assembly time. Also, if one larger bolt could replace several smaller bolts, the same effect would be obtained. Finally, some components might use more fasteners than is necessary. For example top plates, triangle joints or shelves, the number of fasteners in some of these assemblies could in our eyes be reduced. This would allow faster assembly without compromising the rigidity of the cart.

Assembly Station 2

Because of the simple design of the rotating assembly station developed, there are a number of things that need more attention in order to further improve the usability and efficiency of the station. First of all is the need of a faster and easier attachment of the frame to the rotating assembly station. In the prototype this function was made as easy as possible, just using two bolts and two nuts to secure the frame on each side. This operation should be made fast and easy for the operators to use, to facilitate a streamlined assembly.

During the PoC, a play was detected between the bolt that holds the horizontal beam which is attached to the frame of the cart, and the hole in the vertical beam. This play caused instability of the assembly stations and caused difficulties during rotation. This bolt should be exchanged to a larger axle and secured in bearings to prevent instability.

Proper bins for fasteners and tool holders should be attached to both assembly stations to prevent unnecessary movement and searching for misplaced tools. Also, to reduce the need for the assembly worker to hold screws in one hand and assemble with the other. If the fasteners are close, both hands can be used for assembly which facilitates an efficient assembly process. Furthermore, it is recommended to use different colours on the bins to further simplify for the assembly workers to find the correct fastener.

The rotation dollies in the PoC had four wheels, mainly to facilitate movement of the dolly when the frame is detached. This made the footprint of the dollies larger which made assembly harder due to the risk of tripping. If the footprint could be reduced, by for example having a folding base on the dolly so that only two wheels are used when the frame is attached, this would reduce the risk of tripping and thereby the productivity since the assembler does not have to worry about falling while assembling.

Review of the Current Assembly Process

In the earlier described ”fishbone diagram” (Figure 6.7), ”pro’s and con’s in the assembly process” (Appendix G) and ”the eight wastes” (Appendix H), a number of factors are listed which affects the effectiveness and efficiency of the assembly process. Several of these factors have no direct connection to the result presented in this thesis. However, a lot of these factors can be resolved with relatively low investments in both time and capital. Therefore, a recommendation is to start by reviewing these listed factors before investing in a new assembly concept.

References

Peter Almström. Sustainable production systems, January 2015. URL `https://www.youtube.com/watch?v=aJ8hBR8HiyY`. [Video File] Accessed on 21.05.2018.

Zeki Ayağ. An integrated approach to concept evaluation in a new product development. *Journal of Intelligent Manufacturing*, 27(5):991–1005, 2014.

Daria Battini, Xavier Delorme, Alexandre Dolgui, Alessandro Persona, and Fabio Sgarbossa. Ergonomics in assembly line balancing based on energy expenditure: a multi-objective model. *International Journal of Production Research*, 54(3):824–845, 2016.

Michel Baudin. *Lean Assembly: The nuts and bolts of making assembly operations flow*. Productivity Press, 1st edition, 2002.

Cecilia Berlin and Caroline Adams. *Production Ergonomics: Designing Work Systems to Support Optimal Human Performance*. Ubiquity Press, London, UK, 1st edition edition, 2017.

John Bicheno. *The new lean toolbox : towards fast, flexible flow*. PICSIE Books, 3rd edition, 2004.

Geoffrey Boothroyd, Peter Dewhurst, and Winston A. Knight. *Product Design for Manufacture and Assembly*. Taylor & Francis Group, 3rd edition, 2011.

Alan Bryman and Emma Bell. *Business research methods*. Oxford University Press, 6th edition, 2011.

Chalmers. Staff at chalmers university of technology, July 2011. URL `Available: https://www.chalmers.se/en/Staff/Pages/lars-trygg.aspx`. Accessed on 23.02.2018.

Chalmers. Staff at chalmers university of technology, December 2012. URL `Available: https://www.chalmers.se/sv/personal/Sidor/magper.aspx`. Accessed on 15.02.2018.

Chalmers. Staff at chalmers university of technology, November 2013. URL `https://www.chalmers.se/en/Staff/Pages/petera.aspx`. Accessed on 15.05.2018.

Douglas Daetz. *The Effect of Product Design on Product Quality and Product Cost, Quality Progress*. Number 6. Quality progress, 20 edition, 1987.

Robert Damelio. *Basics of Process Mapping*. Productivity Press, 2nd edition, 2011.

Martyn Denscombe. *The Good Research Guide: For Small-scale Social Research Projects*. McGraw-Hill, 5th edition, 2014.

Ann-Christine Falck, Roland Örtengren, and Dan Högberg. The impact of poor assembly ergonomics on product quality: A cost–benefit analysis in car manufacturing. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 20(1):24–41, 2014.

Flexqube. These 3 material handling carts were our customers favourites of 2017, December 2017. URL `https://www.flexqube.com/flexqube-news/these-3-material-handling-carts-were-our-cust` Accessed on 14.05.2018.

Tilda Gaskell. The process of empirical research: a learning experience? *Research in Post-Compulsory Education*, 5(3):349–360, 2011.

Michael L George, David Rowlands, Mark Price, and John Maxey. *The lean six sigma pocket toolbook*. McGraw-Hill, 1st edition, 2005.

E. Gurevsky, O. Hazir, O. Batta'fa, and A. Dol. Robust balancing of straight assembly lines with interval task times. *Journal of the Operational Research Society*, 64:607–1613, 2013.

IEA. Definition and domains of ergonomics, December 2017. URL `http://www.iea.cc/whats/`. Accessed on 18.05.2018.

Hans Johannesson, Jan-Gunnar Persson, and Dennis Pettersson. *Produktutveckling*. Liber AB, 2nd edition, 2013.

Hanna Kallio, Anna-Maija Pietilä, Martin Johnson, and Mari Kangasniemi. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, 72, 2016.

Onur Kaya. Information search and analysis, 2016. Unpublished Lecture Notes, PPU085, Chalmers University of Technology.

Jonathan Law. *A Dictionary of Business and Management*. Oxford University Press, 6th edition, 2016.

David S. Leonard. Does color of warnings affect risk perception? *International Journal of Industrial Ergonomics*, 23(5-6):499–504, 1999.

Andrea Lešková. Principles of lean production to designing manual assembly workstations. *International Journal of Engineering*, pages 31–36, 2013.

Jeffrey K. Liker. *The Toyota way*. McGraw-Hill, 2004.

Management Mania. 5-m method, March 2016. URL https://managementmania.com/en/5-m-method. Accessed on 21.05.2018.

Willem Mertens, Amedeo Pugliese, and Jan Recker. *Quantitative Data Analysis A Companion for Accounting and Information Systems Research*. Springer International Publishing Switzerland, 2017.

Alex Milton and Paul Rodgers. *Product Design*. Laurence King Publishing, 1st edition, 2011.

Ron Moore. *Selecting the Right Manufacturing Improvement Tools*. Butterworth-Heinemann, 1st edition, 2006.

Chris A. Ortiz. *Kaizen Assembly: Designing, Constructing, and Managing Lean Assembly Line*. Taylor & Francis Group, 1st edition, 2006.

Kevin N. Otto and Kristin L. Wood. *Product design: Techniques in reverse engineering and new product development*. Prentice Hall, 1st edition, 2001.

Runa Patel and Bo Davidson. *Forskningsmetodikens grunder*. Lund:Studentlitteratur, 4th edition, 2011.

John. W. Priest and José M. Sánchez. *Product Development and Design for Manufacturing*. Marcel Dekker, 2nd edition, 2001.

PSU. Empirical research in education and the behavioral/social sciences, February 2018. URL http://guides.libraries.psu.edu/emp. Accessed on 18.05.2018.

Colin Robson. *Real World Research: A resource for users of social research methods in applied settings*. John Wiley & Sons Ltd., 3rd edition, 2011.

Parastoo Roghaniana, Amran Rasli, and Hamed Gheysari. Productivity through effectiveness and efficiency in the banking industry. page 550 – 556, 2012.

Simon Algesten. Private communication, 2018. March 15, 2018.

Lena Sperling, Sven Dahlman, Li Wikström, Åsa Kilbom, and Roland Kadefors. A cube model for the classification of work with hand tools and the formulation of functional requirements. *Applied Ergonomics*, 24(3):212–220, 1993.

Linda Strande, Mariska Ronteltap, and Damir Brdjanovic. *Faecal Sludge Management: Systems Approach for Implementation and Operation*. Iwa Pub, 2014.

K.G. Swift and J.D. Booker. *Process Selection From design to manufacture*. Butterworth Heinemann, 2nd edition, 2003.

David G Ullman. *The mechanical design process*. McGraw-Hill/Irwin, 4th edition, 2010.

Karl T. Ulrich and Steven D. Eppinger. *Product Design and Development*. McGraw-Hill, 5th edition, 2012.

U.S.Army. *Human Engineer Design Data Digest.* CREATESPACE, Washington, DC, 2000.

Kim B Wheelwright, Steven C; Clark. *Revolutionizing product development: quantum leaps in speed, efficiency and quality.* Free Press, 1992.

Mohsen Zare. Does ergonomics improve product quality and reduce costs? a review article. *Human factors and ergonomics in manufacturing & service industries*, 26(2): 205–223, 2016.

X.F. Zhaa, H.J. Dua, and J.H. Qiu. Knowledge-based approach and system for assembly oriented design. *Engineering Applications of Artificial Intelligence*, 14(1):61–75, 2001.

Appendices

A Details Regarding Interviewees

Magnus Persson, Associate Professor, Technology Management and Economics at Chalmers

Magnus research is stated to be in the area platform development and modularisation strategies (Chalmers, 2012). Magnus was chosen due to his experience and expertise within modularisation and platform strategies in order to evaluate if this could be used to improve the assembly process.

Lars Trygg, Associate Professor, Technology Management and Economics at Chalmers

Lars Trygg conducts research within the areas technology and product development, where his focus is partly on manufacturing industries (Chalmers, 2011). The reason why Lars Trygg was selected as a qualified interviewee was because he was recommended by Magnus Persson due to his research within DFA which can be used to reduce assembly time.

Peter Almström, Associate Professor, Technology Management and Economics at Chalmers

Peter Almström is an associate professor within production analysis. He teaches mostly in production management, productivity management and work place analysis & design (Chalmers, 2013). Peter has a special interest within manual work and is also teaching in a course which uses components from Flexqube to analyse assembly productivity which made him a good interviewee.

Simon Algesten, SPS Manager Scania Engine Assembly (Lean)

A telephone interview was performed with Simon Algesten who has 19 years of experience working at Scania in Södertälje. Five years as a SPS (Scania Prodution System) and before that various engineering roles withing RD and production. Simon was interviewed due to recommendations from other contacts with connections to Scania and due to his role where he is partly working with streamlining the assembly process in engine assembly.

Anders Carlsson, CTO, Modul-System AB

An interview was held with Anders Carlsson who is the CTO of Modul-system. Anders was chosen as an interviewee due to the similar challenges that both Flexqube and Modul-system face regarding variation between product solutions, vast number of solution combinations and their manual assembly process.

Olof Henriksson, Logistic Technician at Volvo Trucks

An interview was conducted with Olof Henriksson who has seven years of experience working at Volvo Trucks in Tuve. Olof was reached through the contact network at Chalmers and fit well due to his experience with the internal logistics at the assembly plant.

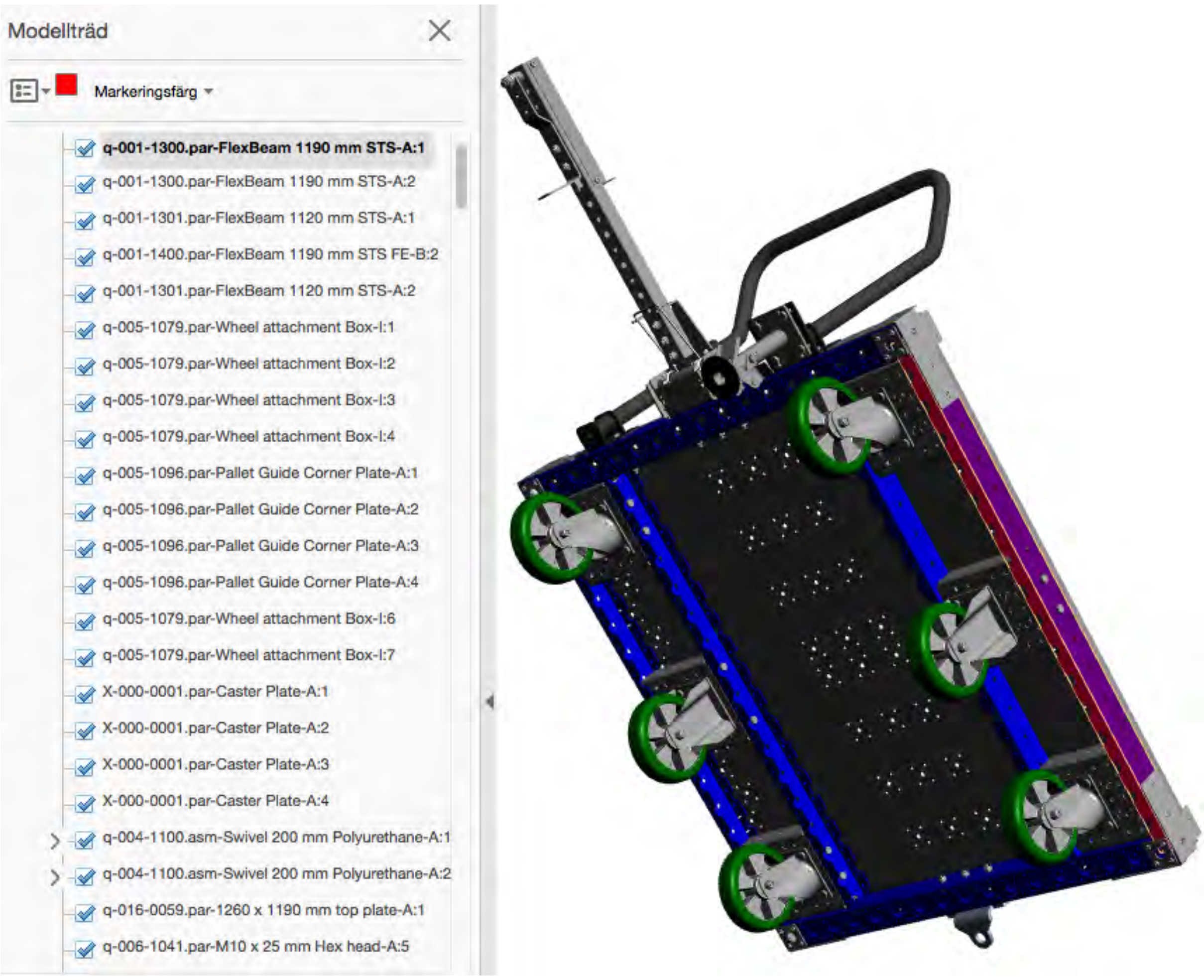
Wesley Worthen, Assembly Manager, Georgia, USA

Wesley has the role as an assembly manager where he is responsible for the assembly of the low volume production line, prior to that he was also responsible for the internal logistics for Flexqube's parts. Wesley were chosen due to his experience assembling Flexqube carts and his holistic view of the whole assembly process.

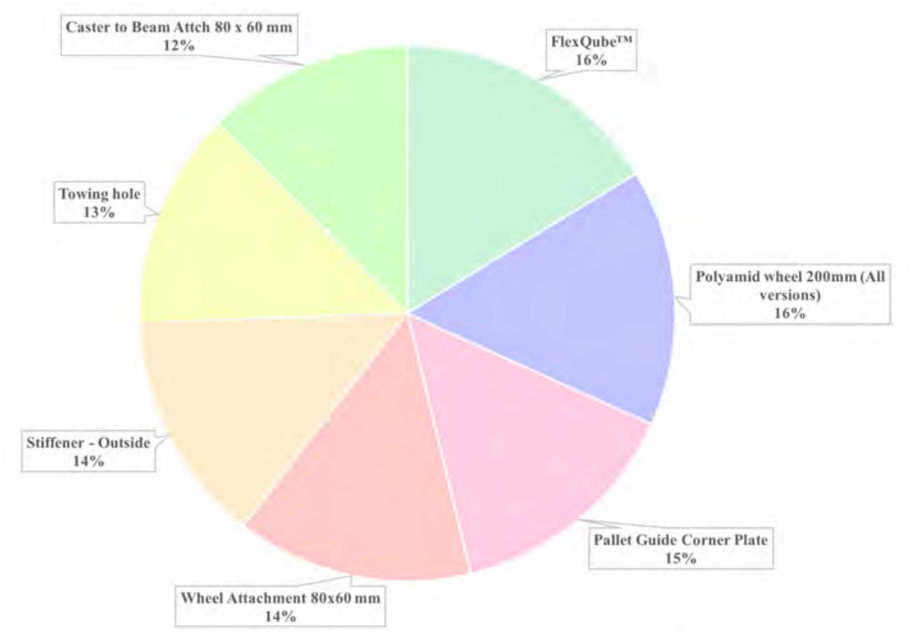
Jeff Watson, Assembly Manager, Georgia, USA

The interview with Jeff was conducted subsequently to the one with Wesley and included identical questions and duration. Jeff is the assembly manager of the high volume production line, which means that he is responsible for the assembly of the carts where variation is lower but volume higher. Similar to Wesley, Jeff was chosen due to his experience of the assembly process and assembling of Flexqube's carts.

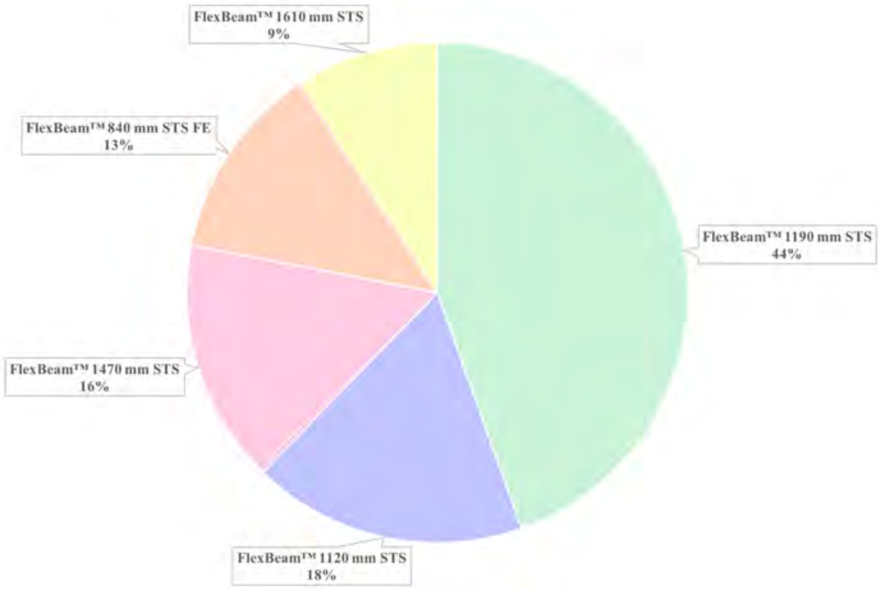
B 3D-pdf


Modellträd
Markeringsfärg
q-001-1300.par-FlexBeam 1190 mm STS-A:1
q-001-1300.par-FlexBeam 1190 mm STS-A:2
q-001-1301.par-FlexBeam 1120 mm STS-A:1
q-001-1400.par-FlexBeam 1190 mm STS FE-B:2
q-001-1301.par-FlexBeam 1120 mm STS-A:2
q-005-1079.par-Wheel attachment Box-I:1
q-005-1079.par-Wheel attachment Box-I:2
q-005-1079.par-Wheel attachment Box-I:3
q-005-1079.par-Wheel attachment Box-I:4
q-005-1096.par-Pallet Guide Corner Plate-A:1
q-005-1096.par-Pallet Guide Corner Plate-A:2
q-005-1096.par-Pallet Guide Corner Plate-A:3
q-005-1096.par-Pallet Guide Corner Plate-A:4
q-005-1079.par-Wheel attachment Box-I:6
q-005-1079.par-Wheel attachment Box-I:7
X-000-0001.par-Caster Plate-A:1
X-000-0001.par-Caster Plate-A:2
X-000-0001.par-Caster Plate-A:3
X-000-0001.par-Caster Plate-A:4
q-004-1100.asm-Swivel 200 mm Polyurethane-A:1
q-004-1100.asm-Swivel 200 mm Polyurethane-A:2
q-016-0059.par-1260 x 1190 mm top plate-A:1
q-006-1041.par-M10 x 25 mm Hex head-A:5

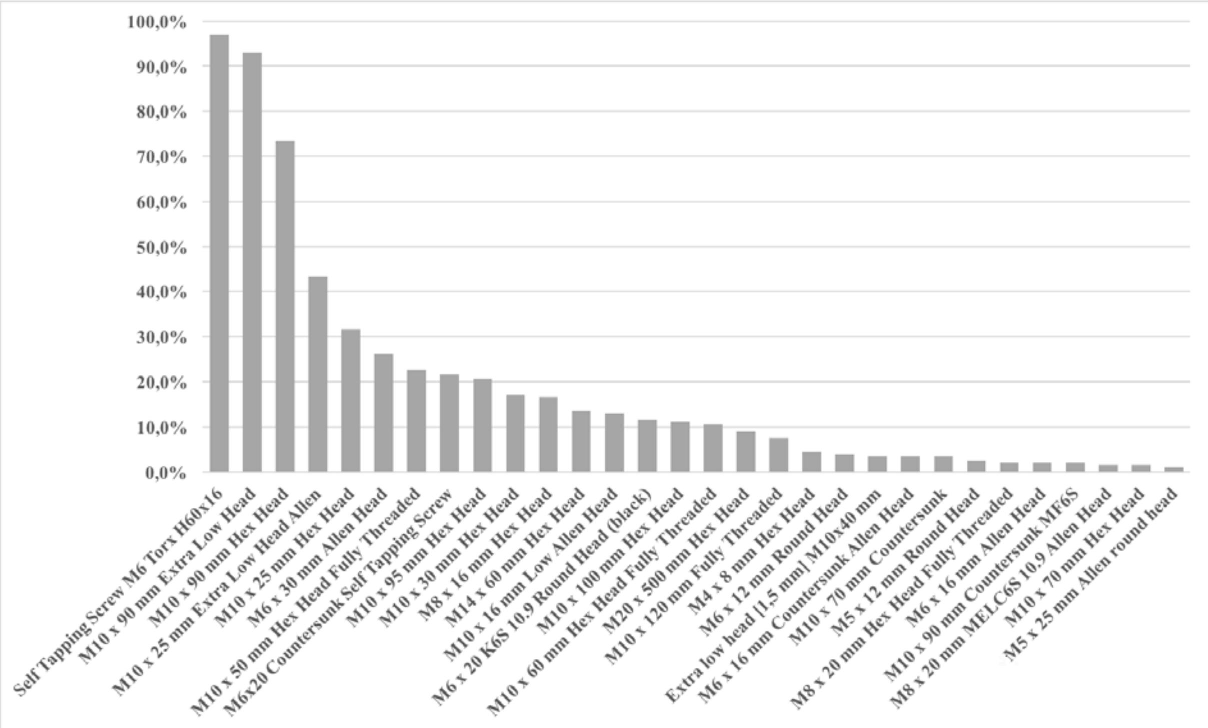
C Components (other)



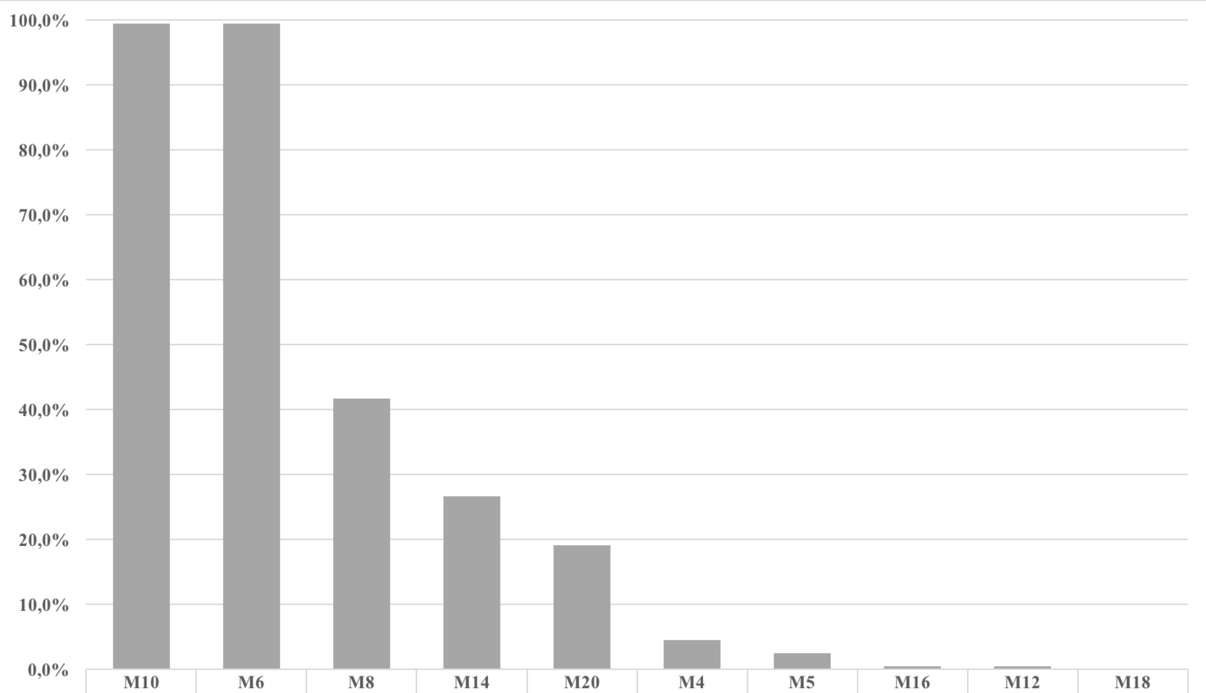
D Most Used Flexbeams^{TM}



E Statistics of All Bolts



F Statistics of Bolt Type



	M10	M6	M8	M14	M20	M4	M5	M16	M12	M18
%	99,5%	99,5%	41,7%	26,6%	19,1%	4,5%	2,5%	0,5%	0,5%	0,0%

G Pro's and Con's in the Assembly Process

Picking

PRO's

Scale helps to count screws/nuts
Labelled components
Labelled screws/nuts
Correct number of components (less risk of carts missing components)
Q-stock has numerical order for components
Some high volume components close to assembly
Only low volume component at the top

CON's

Messy screw/nut assortment
Unlogic Q-numbers
Time consuming
A lot of air in between storage shelves
Labels for components unattached - risk of getting lost
Hard to bring down several components if using ladder
Q-number does not foretell what you are looking for
Fork lift to reach components
Double work to pick flexbeams, screws, nuts (high volume)
Poor kit carts
Plastic bag for nuts (environmental and cost)
Hard to pick nuts/screws from plastic bag at assembly
Long distance to production line
Q-number for screws hard to see

Part transportation

PRO's

High volume components direct to production line

CON's

Forklifts to transport
Hard to know when to refill components
Has to stop work for refill of components

Material Presentation

PRO's

Labels with Q-number on components (AMC)
Components in proximity of assembly line
To some extent, kit carts are being used
Plastic containers for screws and nuts
Labels with Q-number, name and image on kit cart

CON's

Hard to find correct hole in beam for assembly
Distance to components
Hard to reach components in bottom of pallets
Unused space next to assembly line
No labels on components in shelves
Components stored on floor
Unused space in shelves
Wrapping left on pallets with components
Too large size of container versus size of component
Q-number disappears when wrapping is removed
Flexbeams not in the same height as station 1

Tool presentation

PRO's

Few tools

CON's

Tools has no place (standard placement)
Easy to forget placement of tools
Long distance to charging station, no local station
Have to pause tools on floor

Station 1

PRO's

Flat surface for frame assembly
Soft surface to prevent scratches
Usage of Flexqube carts
Table moves easily
Space in the middle for screws
Large surface fits many frames

CON's

Must walk around table
Screws and nuts dispersed on table without order
Hard to reach center of table
Can not adjust height
Tools paused on table - blocks and hard to reach
Heavy lifting
Dependent on station 2
Distance to computer
Needs to be 2 persons lifting
Limited for special carts / large carts

Station 2

PRO's

Table allows for mounting underneath cart
Easy to move
Soft surface to prevent scratches
Flexqube cart
Mounting available at all sides on cart

CON's

Poor mounting angles (ergonomic)
No storage for screws/tools close
Heavy lifting
Top plate lifting
Screwing from underneath
Distance to computer
Limited for special carts / large carts

Station 3

PRO's

Enables assembly of components high up
Flexible for all type of carts

CON's

Based on the floor
Bad ergonomics
No designated space
Heavy to lift down
No aid to mount vertical beams, needs 2 people

Storage (before shipping)

PRO's

Stacking to save space
Wrapping to prevent damage

CON's

Not using tow bar for transport
Transporting manually one at a time (assembler)
Have to modify pallets to fit wheel base
Interrupting/blocking assembly work
Distance to storage
Occupies space

H The Eight Wastes

Inventory

- No 5S implementation
- Lack of material stock at assembly station
- Hard to find components when picking

Over-production

- Assembly continues even though all components are not present
- Double check screws & bolts

Over-processing

- Too many screws (e.g. top plate)
- Handlebar too tight in attachment
- Holes for screw in flexbeam too tight after paint

Waiting

- Waiting for others: station 1 done before station 2
- Material flow: disrupting assembly process when refilling with forklifts
- Wait for missing components

Motion

- Reach for bolts, nuts etc
- Lifting from one table to another
- Lifting cart to floor
- Reaching for misplaced tools
- Mounting from underneath
- Stacking finished carts
- Reach for components in the bottom of pallets
- Holding components with one hand while assembling

Defects

- Mounting of parts even though not correct (e.g. wrong length of tow bar)
- Forgetting placement of collets
- Mounting wrong spring for the tow bar
- Asymmetric parts (e.g. top plate has to be mounted in a specific orientation)
- Do not know where certain components should be mounted
- Top up the paint due to scratches
- Parts missing in the order list
- No labels on parts to identify them. Punched in at manufacturing?
- Counting holes on flexbeam. Punched markings to identify hole?
- Easier to miss attachment of self tapping screws if not counted
- Wrong placement of stickers

Skills

- Low usage of Flexqube's carts and vision
- High turnover of staff - poor ergonomics?

Transport

- Walking to the computer to look at the 3D-pdf
- Fetch tools
- Pick up material
- Pick up components
- Charge batteries
- Walk around the table when assembling
- No space for finished carts
- Long distance to walk with completed cart

I Paper-based Physical Mock-ups

J Elimination Matrix

Solution	Solves problem	Feasible	Safe	Ergonomic	Uniqueness
A	+	-			
B	+	+	+	-	
C	+	+	-		
D	+	+	+	+	-
1	+	-			
2	+	+	+	+	+
4	+	+	+	+	-
5	+	+	+	+	+
6	+	-			
7	+	-			
8	+	+	+	-	
9	+	+	+	+	+
11	+	-			
12	+	+	+	+	-
AD	+	-			
A1	+	-			
A6	+	-			
BD	+	+	+	+	+
B1	+	+	+	-	
B8	+	-			
B11	+	-			
B12	+	-			
CD	+	+	-		
C5	+	+	-		
C11	+	-			
D5	+	+	-		
D7	+	-			
D11	+	-			
15	+	+	-		
16	+	-			
17	+	-			
2-11	+	-			
2-12	+	-			
4-5	+	+	-		
4-9	+	-			
4-11	+	-			
5-6	+	+	+	+	+
5-12	+	+	+	-	
6-8	+	-			
6-9	+	-			
6-11	+	+	+	+	+