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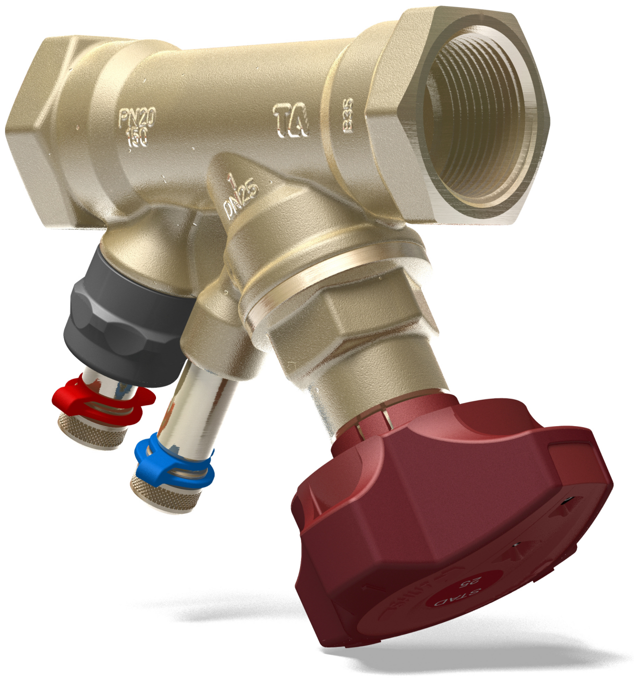

Product design changes for automatic assembly

A case study for finding automated assembly solutions

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ABSTRACT

This project is performed at IMI Hydronic Engineering in Ljung, which is one of the world's leading companies in HVAC systems. IMI Hydronic Engineering is one of the three divisions in the IMI PLC group and has experience in more than 100,000 projects worldwide.

The purpose of this project is to improve the STAD product of IMI Hydronic Engineering for automatic assembly in form of design changes through the concept of Design for Assembly. It is chosen to perform the study in Ljung under the guidance of the research and development department, which enables experience from employees along with relevant documents and data. The DYNAMO ++ method is used as a base and adjusted to suit the issue of this study to evaluate the Level of Automation in the current assembly.

Throughout the DYNAMO++ method and Design for assembly, parts that is difficult to assemble and tasks with low level of automation is identified.

The conclusion made when performing this study is that the design of the product today is containing many parts like washers and O-rings, which are difficult to assemble. Therefore the current design requires large investments in equipment to acquire a higher Level of Automation of the assembly. Instead the concept of Design for Assembly should be applied in the early design stages of a new product to minimize the investment in equipment for an automatic assembly. The use of Design for Assembly in this specific case resulted in a total reduction of parts by nine and a more assembly friendly design of the product.

ACKNOWLEDGMENT

Firstly we would like to thank IMI Hydronic Engineering in Ljung for letting us perform our study there. We would also like to send our gratitude to the research and development department for providing us with office space and materials needed for the project. We send our gratitude to the staff in research and development for making us feel welcome.

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Nomenclature

DYNAMO++	Methodology used for analysing the potential for automation in an existing system.
HTA	Hierarchical Task Analysis
BOM	Build of Material
LoA	Levels of Automation
DFX	Design for X
DFM	Design for Manufacture
DFA	Design for Assembly
DFAA	Design for Automatic Assembly
DFA2-Index	Design for Automatic Assembly Index
VSM	Value Stream Mapping
STAD DN 50	STAD Dimension 50 millimetres

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1. INTRODUCTION

This chapter will define the current problem as well as the analysis of it. The problem will be explained throughout the background, mission and the determined delimitations along with the project questions to obtain a greater understanding of the issue.

1.1 Background

The need for automatic processes is increasing in today's industry. Therefore it is a necessity for major companies to implement modern innovations, such as automatic assembly, to be competitive.

Evolvement from manual to automated assembly is often viewed as a single step process, although the transition consists of several steps and factors that need to be considered. A structural and comprehensive method is necessary to achieve the desired results.

IMI Hydronic Engineering produces a lot of different kind of products for HVAC systems and is one of three divisions of the IMI group. The company is the leading global provider and a recognized expert in hydronic distribution systems and room temperature control, with experience in more than 100,000 construction projects worldwide. During the year of 2014 the company launched 14 new products and obtained calculated revenue of 284 million pounds.

Most of the products have been designed for manual assembly and after product introduction there is sometimes a wish for automatic or semiautomatic assembly to reduce cost in production along with gaining an even product quality. The change from manual to automatic assembly usually generates high expenses and the end result usually does not meet the expectations. Usually it also generates extra work to make it function properly.

At present, the assembly equipment is built to function with the existing design of the details because changes in the details often generates a lot of extra work caused by additional testing of the product functionality to meet the original specifications. Therefore improvement and changes in details are often discarded as a result of low flexibility in today's assembly process.

1.2 The project at IMI Hydronic Engineering

The project of finding an automated solution at IMI Hydronic Engineering by using the STAD-valve as a reference point had the ability to both increase and decrease in size. This was based on the number of people involved as well as the available time.

Because of the company's wishes and other factors, such as the available amount of time and the number of participants in the project was set to three. The project was to be seen as one although the result will be presented in two different separate theses. It is recommended to study both in order to completely understand the complete solution.

This thesis will cover the first part of the project, thus should the second be read after this one

However it was an important part to preserve the ability to be able to read the theses to understand the result, thus some parts will end up the same in both reports. The first three chapters will consist of similar content with limited difference while the empiric along with the discussion chapter will reflect the different areas studied in each report.

1.3 Mission

The mission with this thesis is to examine an existing product of IMI Hydronic Engineering, the STAD DN 50, and investigate the possibilities for design change in order to ease the assembly process. Throughout a structural method the current state of the product´s assembly process will be mapped to identify possible improvements to gain a higher level of automation. Chosen methods will be thoroughly evaluated and adjusted to be suitable for the specific product in this study.

The method used for the STAD DN 50 will act as an example to be applied on a broad range of future products and processes regarding automatic assembly.

1.4 Delimitations

There is a large quantity of products at IMI Hydronic Engineering and a limited amount of time. In order to be able to make a full analysis of the process the main focus will be on one product, the STAD DN 50, and not on an entire product family. The final stage of packaging the products will not be analyzed due to the time limitation of the project.
Because of long lead times associated with producing prototypes the primary visualization will be with solid modeling.

1.5 Project questions

Is there an applicable method for this project regarding automatic assembly ready for use?

- If not, how will it be adjusted to suit this product and process?
- Is it possible to use this method for future products and designs at IMI Hydronic Engineering?

What problems with design and construction will appear when implementing the chosen method on the product STAD DN 50?

What changes can be done to the product with design for assembly in mind?

2. METHOD

A structured method needs to be chosen to achieve relevant results. This chapter will explain the methodology regarding Dynamo++along with other tools and methods used for the accomplishment of the results.

2.1 Information gathering

To gather necessary and relevant information several methods were used to give a good perspective of the current state at IMI Hydronic Engineering regarding the STAD product. Furthermore, a theoretic information foundation covering parts of automation is required to give a better understanding of the issue.

2.1.1 Observation

Observation is an objective method to gather information about processes and objects of interest according to Osvalder et.al. (2010). The purpose of the observations is to get a better understanding of a process in its natural environment without influencing the execution of it.

Direct and indirect observations are two ways to gather information of a process whereas direct observation is when the observer is present in the process environment. When performing an indirect observation the observer is instead using a fictional environment such as films to collect relevant data, Osvalder et.al. (2010). Observations can also be regarded as when the observer participates in the process, so called inside observations while outside observation involves an neutral observer collecting data.

The assembly of the STAD being located at IMI Hydronic engineering in Poland enabled only outside observations in this project. Indirect observations were made through films along with other documents sent from personal stationed in Poland. Analyses of the films were used in the process to map the current state of the assembly process. Documents containing information about downtimes, cycle times and numbers on scraped products was important to map the current process along with information gathered from Avix-analyzes.

Direct observations were also performed at IMI Hydronic Engineering in Ljung on similar products to gather relevant information. The products in question are mainly the STAF-valve and also the COMPACT-valve that have similar structure.

The most similar part would be the bonnet of the STAF between dimensions 25-50 millimeters, which is identical with the bonnet of the STAD. Therefore it is relevant to observe the assembly at Ljung to obtain information and analyze it for the method used on the STAD.

2.1.2 Interviews

To acquire a broader perspective of the process interviews with engineers was performed. This information gathering was necessary to find problems that easily are overlooked when analyzing films or observing documents as well as drawings.

There are three different types of interviews according to Osvalder et al. (2010), unstructured, semi-structured and structured interview. In the first, unstructured, the interviewer asks open questions to the person being interviewed. This way, the person being questioned, has the choice to steer the interview at a direction he or she feels as important. This form of interviews is best suited for situations where the person performing the interview has limited knowledge of the subject at hand and is depending on the person being questioned to explain and include important facts. The upside of unstructured interviews is that the person interviewing has the ability to follow up interesting questions with discussion regarding the subject. The downside of this type of interviews is that the answers can be difficult to compile and compare.

Structured interviews is based on questions created before the interview and the person being interviewed can either answer the questions with an answer or with the help of a grading scale e.g. from 1-5. In order to be able to use structured interviews the interviewer has to have good knowledge of the subject at hand in order to create relevant questions. The upside of this method is that the answers collected is often easy to compile and compare as well as it often is straight and clear answers not up for interpretation. The downside is that the flexibility is lower than other methods and there is no or little room for change during the interview itself.

A semi-structured interview is as it sounds a mixture between the two other methods. Before the interview starts a structure has been created and the subjects that are to be discussed has been decided. However, the interviewer can during the interview choose what areas of the subject he or she wants to discuss and what questions to ask. The possibilities for follow up questions remains in this method in the same way as in unstructured interviews. The interviewer has to have basic knowledge of the subject at hand and know what areas that are important. The upside of this method is that the flexibility of unstructured interviews still exists while the interview it self still is structured and gives relevant information since it is prepared in advance.

In this project the chosen method of performing interviews is semi-structured since the participants has basic knowledge of the product as well as the process. The advantage of being able to steer the interview and maintain the possibility for open questions is important in order to not overlook significant areas were expertise is needed.

2.2 The Dynamo method

Determining the Levels of Automation of a chosen system is a part of the Dynamo++ method. Dynamo++ is also used to find ways to change the levels according to situational needs and wishes. The methodology is a further development of the DYNAMO method, which was introduced in 2004, Fasth (2012), and was utilized in seven case studies. The rework of the DYNAMO method between 2007-2009 resulted in DYNAMO++ where four case studies was formed for the development of the method, and six cases for validation according to Fasth (2012).
The method consists of 12 steps that are divided in four phases with three steps each. The phases and steps are as follows:

Phase 1) Pre study:

1. Choose system
2. Walk the process
3. VSM, identify the time and flow parameters

Phase 2) Measurement:

4. Identify the main operations and subtasks. Design a HTA of the chosen area
5. Measure LoA (both physical and cognitive)
6. Document the result

Phase 3) Analysis:

7. Workshop to decide the relevant Min- and Max levels of automation for the different tasks
8. Design of the SoPI (Square of Possible Improvements)
9. Analysis of the SoPI, task and operation optimization due to the time and flow parameters

Phase 4) Implementation:

10. Write and visualize suggestions of improvements based on the SoPI analysis
11. Implementation of the chosen suggestions
12. Follow-up when the suggestions have been implemented to see what effects the suggestion has had on time and flow parameters

The presented phases and steps will culminate in a better understanding of the chosen process and enlighten problems within the system. Also the methodology consists of several tools such as HTA (Hierarchical Task Analysis), DFA (Design For Assembly) and line balancing, used to increase or decrease the Levels of Automation avoiding under – or over automated systems. Multiple iterations of the method, illustrated in figure 1, will give better results.

This study covers the steps of one to seven with the added the tool of DFA2- index while the later steps is covered in the previously mentioned second report.

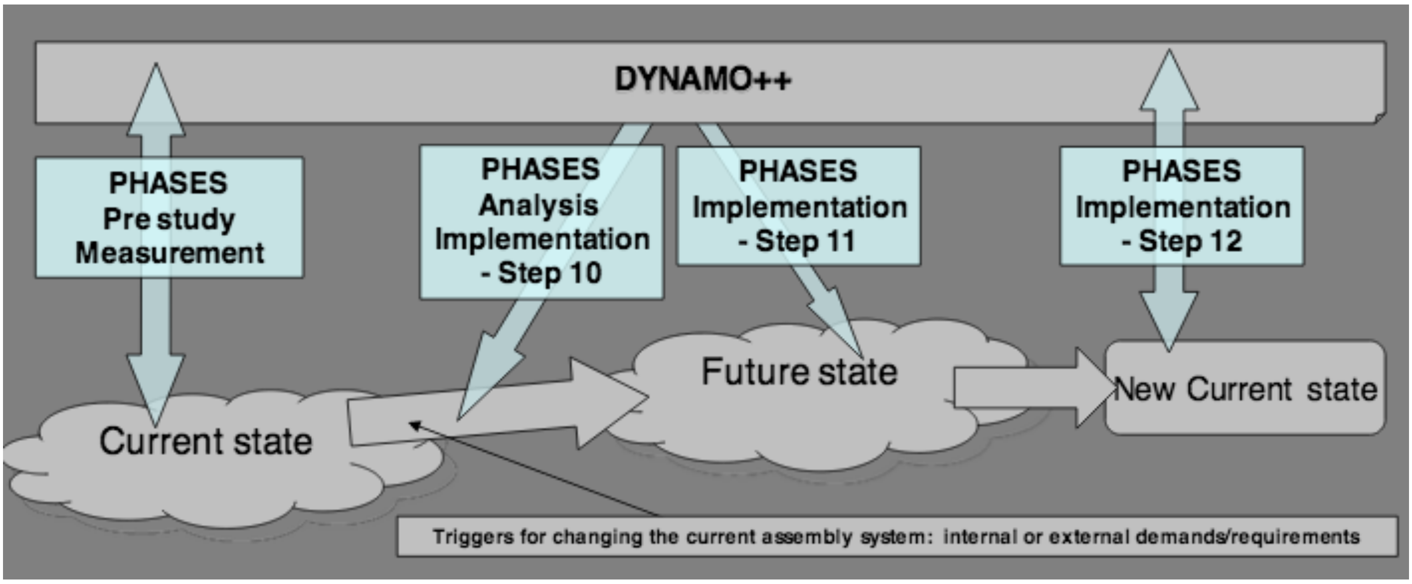


Figure 1 – Phases of Dynamo++ method

Figure 2 presents an alternative illustration of the method featuring some tools used during the execution of the method. The figure also visualize that some of the steps are not necessarily bound to a specific phase but instead used to the extent that the project requires.

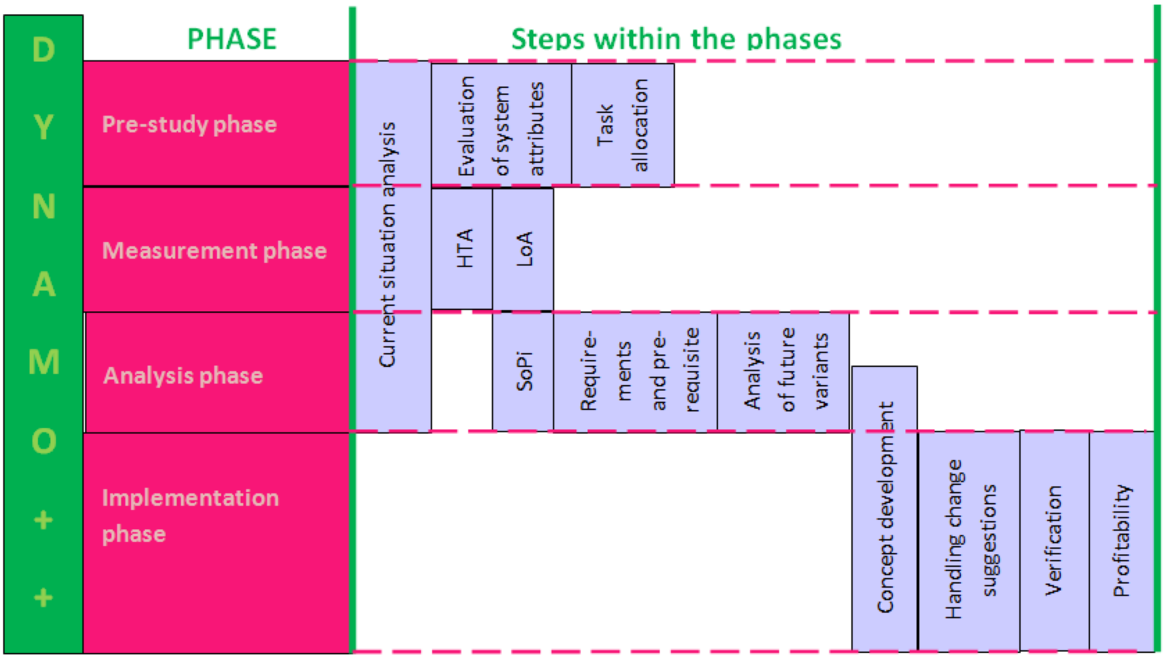


Figure 2 – Another interpretation of the phases of the Dynamo++ method

2.3 Design For Assembly

One tool used in the Dynamo++ method is Design for Assembly, DFA. The Dynamo++ method suggests that DFA is used after the LoA-measurement phase. The tool is used to increase the possibilities for higher level of automation. This tool has a significant and central role in this project both because it is an effective tool as well as a wish from the company in order to optimize the product for assembly.

In order to choose, create and/or compile a viable DFA method, theoretical research had to be done while considering several recognized researchers different views on the subject. When using DFA as a method to improve a product for assembly there are guidelines that have to be followed. A complete list of these guidelines had to be compiled and is presented in the theoretical chapter along with a tool called DFA2-index created by Stephan Eskilander (2001).

2.4 Validity and reliability

The term reliability can describe to what extent someone else outside of the original project can repeat the result. Validity consists of two different parts, the first one is internal validity and the second is external. Internal validity is a measurement of how the result describes the reality. External validity describes how well the result can be generalized (Merriam, 2006).

The result of this project has been compared and matched to the theory regarding the studied areas as well as discussed with operators, engineers and management in order to ensure its validity.

3. THEORY

This chapter provides necessary knowledge for better understanding of encountered subjects in this thesis. The chapter explains the theory behind the method used to accomplish the results.

3.1 Automation

The word automation has number of different meanings and differs from person to person. In order to use the word automation it is important to define the word, as it will be used in this thesis. Along with the definition of automation the advantages and disadvantages will be discussed.

3.1.1 Definition of automation

The first automated system was a basic machine that replaced one single manually performed operation by using an electrical motor connected to a mechanism that could perform one single static task. Using a system like this gives no feedback to the user and does not have any possibilities for automatic error correction.

Sheridan (2002) says that the definition of the word automation has probably changed over time since the word first was used.

The definition: “using automatic control to manufacture a product” is according to Sheridan (2002) vague. Sheridan instead uses the definition: “automation is the application of automatic control in all types of industries and in scientific areas”. This is the current and most accepted definition of automation even though, according to Sheridan (2002), there is a third one getting increasingly more acceptance in today’s industry and science: “automation is the use of electronics and mechanics to replace human interaction”.

By human interaction Sheridan (2002) means both the physical work a human perform as well as the gathering of information (artificial sensors), decision making (computerized) and the communication between human and machine or machine to machine.

A system like this can be both with and without feedback and according to Sheridan (2002) it can be visualized as shown in figure 3.

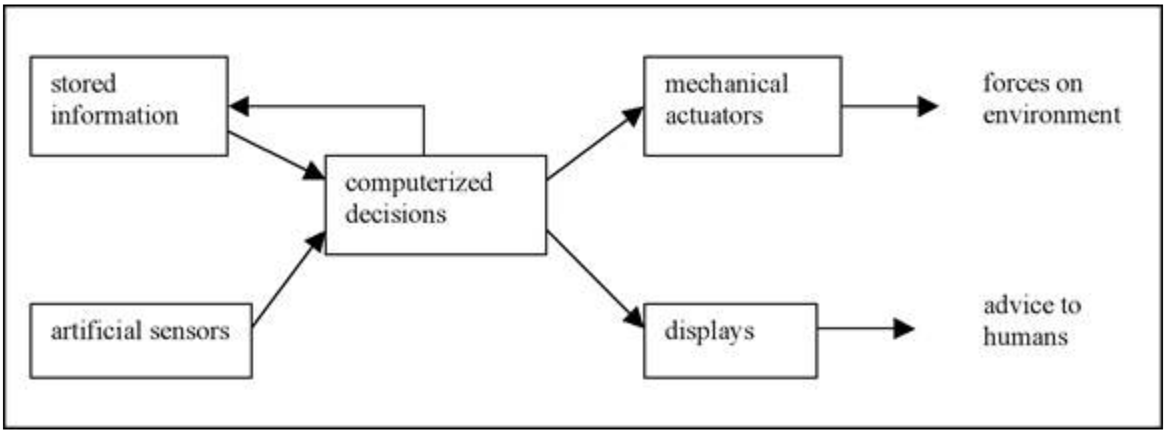


Figure 3 - Sheridans (2002) view of an automatic system

3.1.2 Levels of Automation

The simplest way to observe automation is in the aspects of either manual or automatic Frohm (2008). This observation gives the impression that manual labor evolves to fully automatic in a single step although the process from manual labor to fully automatic is more complicated. There is therefore a need to observe automation in more than two modes for a more accurate definition of a systems automation level. There are several definitions of the concept Levels of Automation by a number of authors and is often described as an interference between human and machine. Whereas the Levels of Automation is defined by the amount of assistant needed from a human for the machine to be able to complete a task. Kern and Schumann (1985) describes it as: "Degree of mechanization is defined as the technical level in five different dimensions or work functions". Though, Sheridan (1980) describes Levels of Automation as: "The level of automation incorporates the issue of feedback as well as relative sharing of functions in ten stages". It is seen that the definitions of Kern et.al. and Sheridan differ from one another, but it does not mean that one of them are mistaken. The authors are explaining different type of automations as Sheridan describes the levels of computerization, meaning human-computer decision making during a task. Kern and Schumann are instead describing the mechanical level of automation; meaning at which level the machine is executing the task by its own. Frohm (2008) defines Levels of Automation as: "the Allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic". By physical task Frohm (2008) means the level of automation for mechanical activities, while the cognitive tasks means the automation of information Fasht (2009). Frohm´s (2008) definition recognizes that both of the descriptions presented by Sheridan and Kern, Schumann is important to determine a systems level of Automation. Therefore both the informational together with mechanical automation need to be reviewed separately whereas the two automation types then decide the level of automation presented in an evaluation matrix.

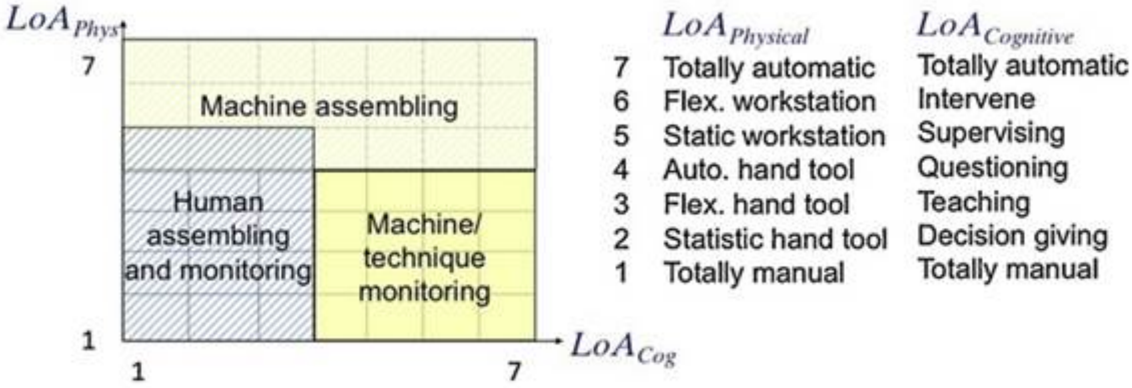


Figure 4 - Explanation of the different Levels of Automation, Fasth (2009)

The suggested matrix orders the physical and cognitive tasks in seven steps presented in figure 4 and are assessed to define the level of automation. The measurement methodology can act as a base to estimate the potential of automation and technology of a manufacturing system (Frohm 2008).

In figure 5, Frohm (2008), explains the seven levels of automation in both physical and cognitive activities for a better understanding of the differences between them.

LoA	Mechanical and Equipment	Information and Control
1	**Totally manual** - *Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power*	**Totally manual** - *The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge*
2	**Static hand tool** - *Manual work with support of static tool. E.g. Screwdriver*	**Decision giving** - *The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order*
3	**Flexible hand tool** - *Manual work with support of flexible tool. E.g. Adjustable spanner*	**Teaching** - *The user gets instruction on how the task can be achieved. E.g. Checklists, manuals*
4	**Automated hand tool** - *Manual work with support of automated tool. E.g. Hydraulic bolt driver*	**Questioning** - *The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action*
5	**Static machine/workstation** - *Automatic work by machine that is designed for a specific task. E.g. Lathe*	**Supervision** - *The technology calls for the users' attention, and direct it to the present task. E.g. Alarms*
6	**Flexible machine/workstation** - *Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine*	**Intervene** - *The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat*
7	**Totally automatic** - *Totally automatic work, the machine solve all deviations or problems that occur by it self. E.g. Autonomous systems*	**Totally automatic** - *All information and control is handled by the technology. The user is never involved. E.g. Autonomous systems*

Figure 5 - Definition of the different levels of automation, Frohm (2008)

3.2 Hierarchical Task Analysis

The hierarchical task analysis is a method that can be used to structure a main task into subtasks to be able to understand the task and how it is supposed to be performed (Stanton, 1999). The HTA is used to provide a detailed overlook of the process an operator need to do before the main goal of the task is achieved.

The easiest ways to gather the data required to create a HTA is by conducting interviews and observe the process while it is being executed during production. Also already existing work instructions and manuals can be used to collect needed data. The first step of HTA is to identify the goal of the process, in this case the finished product. The main goal is later divided into sub tasks that must be completed to reach the main goal.

When a main goal and the sub tasks required reaching the goal is defined, the sub tasks is later divided into operations. This is being iterated until the level of details desired of the HTA is reached. An example of a HTA is shown in figure 6.
The operations are placed at the lowest level in the HTA and can contain two types of information. Whereas the two types of information is the action itself required to achieve the task, for example press the red button, and the second type of information being the goal of the operation, and for example stop the engine, Osvalder (2010).

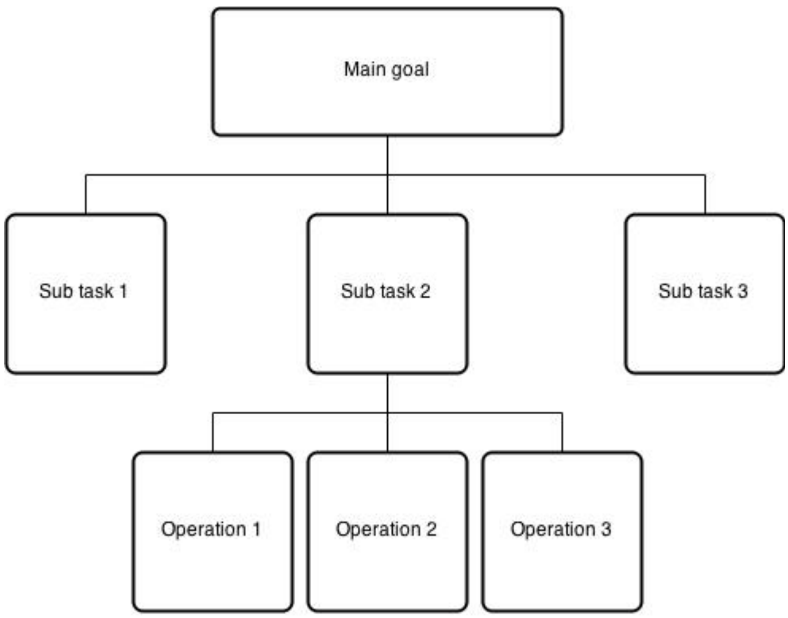


Figure 6 - Example of a HTA

3.3 Design for X

Design for X, DFX is the collective name of methods that can be used when designing products or parts. The purpose of methods that can be placed within the area of DFX is to focus on different phases of a products life cycle or a specific property. Several advantages can be found when using DFX such as lower design costs and early discovering of environmental effects, Eskilander (2001).

As mentioned DFX is a collective name for methods (presented in figure 7) and the two most common methods used in DFX is Design for Assembly (DFA) and Design for Manufacture (DFM).

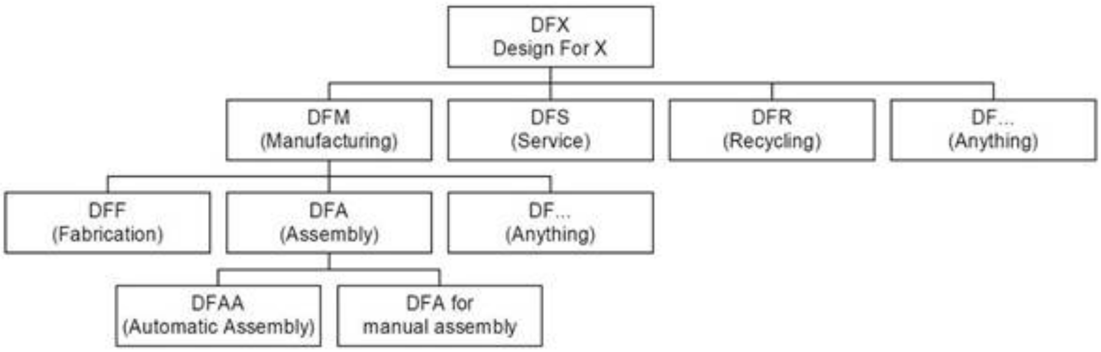


Figure 7 - The hierarchical structure of DFA, DFAA and DFM among other DFX-methods, Eskilander (2001)

3.3.1 Design For Manufacture

Design for Manufacture is according to Boothroyd et al. (2011) a method which purpose is to make manufacturing more effective and easier by creating a product based on manufacturing conditions. Fabricius (2003) agrees and also states that DFM starts during the conceptual design stage and ends during the detailed design stage.

DFM can according to Fabricius (2003) be measured by manufacturability, which in its turn has seven aspects to measure. These seven aspects are as follows: Direct and indirect production costs, quality, flexibility, risk, lead-time, efficiency and environmental effects.

The general idea of DFM is to increase feedback between different departments with in the company, such as design departments and manufacturing departments. This should be done in order to improve manufacturability already during the design stage of a product.

3.3.2 Design For Assembly

Design for Assembly is a method that is used to evaluate and analyze parts of a product. This should according to Boothroyd et al. (2011) be a part of the complete process of designing a new product but is best done during the early stages when designing or redesigning a product. The construction engineers and design team should use DFA to evaluate and simplify every part of a new product in order to simplify the assembling and reduce the assembly time.

The DFA method contains a set of basic and general design guidelines, which according to Boothroyd et al. (2011) can be divided into two groups:
Guidelines for part handling, containing five guidelines:

- The parts should be designed to have end-to-end symmetry as well as rotational symmetry around the axis of insertion.
- If designing a part to be symmetric is not possible then design it to be clearly asymmetrical.
- Features to prevent jamming of parts nesting and stacking when stored in bulk should be implemented in the design.
- Features to prevent tangling of parts when stored in bulk should be implemented in the design.
- Parts that stick together or are slippery, delicate, flexible, very small or very large, or in any case are dangerous to the operator should be completely avoided in the product design.

Guidelines for insertion and fastening, containing seven guidelines:

- The design should be so there is as little resistance to insertion as possible and also provide chamfers that will work as a guide for insertion of two parts.
- Standardize as much of a product as possible, even across product lines. Using common parts, methods and processes across product lines is doing this in an easy way.
- Use pyramid assembly, often best to assemble from above and about one axis of reference.
- Avoid the need to hold down parts during assembly to maintain the position while another part is being put into place. Design the parts so that they are self-locating while other parts are being assembled.
- A potential source of problems in placing parts during assembly is when the design dictates the need to release a part before it is located in the right place. This should be avoided by design.
- When using common mechanical fasteners the following order should be considered, the first on being the most cost efficient: snap fits, twist tabs, rivets and threading.
- When a fixture is used to keep the parts in place during the assembly process, avoid the need to reposition it for further assembly.

3.3.3 Design For Automatic Assembly

Design for automatic assembly is a method based on DFA and is used in the same way since it is always simple to manually assemble a product that is easy to assemble automatically, Eskilander (2001). DFAA has the same approach as DFA with the important exception that DFAA has its focus on automatic assembly.
An important part of DFAA is that the design team has to take into account that the flexibility of an automatic system in almost every case is lower than the flexibility of humans. The consequence of this is that the rules of the traditional DFA have to be followed more precise in order to use the maximum flexibility of an automated assembly system.

3.4 DFAA-Index

DFAA-index, henceforth known as DFA2-index, is a tool that can be used for evaluation and visualization of hazards when designing a product that is to be assembled semi- or full automatic.

The DFA2-index has its base from the rules Boothroyd et al. (2011) created, although they are here measured and leveled with a point scheme and strictly seen from an automatic assembly perspective:

- What is considered the best solution is scored with 9 points.
- A good and acceptable solution for the problem that is not completely satisfying is scored with 3 points.
- An unwanted solution is scored with 1 point.

Categories that get scored with 1 point should be redesigned before starting or changing a manufacturing process and is to have the biggest focus when evaluating the product according to Eskilander (2001). A complete list of every category and its evaluation, both what is important to consider and its points can be found in Appendix A.

There are a total of 18 categories that is to be evaluated and at the end all points are summed up in Appendix A. All solutions with a score less than 9 points indicate that the product is not at its maximum potential according to Eskilander (2001). The total score of the product is then divided with the highest possible product score and then multiplied by a factor of 100. This will give the user a score in percentage on how close the product in its current concept is to its ideal solution for automatic assembly process.

$$DFA2 - index\ (\%) = \frac{Total\ score\ of\ product}{Maximum\ ideal\ score}\ x\ 100$$

The method does not require a physical product to be effective. It can be used when the product itself is in the design stage as long as there are sketches and solid models of product. This makes the DFA2-index method useful for product development teams when creating prototypes in order to avoid unnecessary redesign further along in the total creation process of a new product according to Eskilander (2011).

3.5 Current state analysis

A current state analysis is important to perform when planning to implement an automated system. This because knowing the current process and how it works decreases the risk of good ideas get overlooked or even discarded. It is also important to involve all phases of the manufacture process in order to be able to see the overall picture, Bellgran and Säfsten (2002). They also state that doing a current state analysis is not an iterative process, doing the analysis one time generates the required information. The analysis should answer two questions primarily and these are:

- What do we have today?
- What do we want to accomplish?

Answering these questions thoroughly can be done by using a set of tools where the one recommended in the Dynamo++ method is value stream mapping, VSM, Fasth (2008).

3.5.1 Value stream mapping

Value stream mapping, VSM, is a method used to map and visualize the flow of materials and information in a manufacturing process. According to Rother and Shook (1999) the word "value" in this method refers to the value an operation adds to product towards the final customer, meaning for example, the action "tightening screws" adds value while the action "pick up a screw" isn't value adding.
The term "value stream" refers to every operation, both value adding and necessary non-value adding operations, as "pick up a screw", that takes place in a manufacturing process.

The process of doing a VSM analysis consists of four steps, choosing a product or product family, mapping current state, mapping the wanted future state and then creating a plan or method to implement the chosen changes.
One of the most important parts of this analysis is to compare and examine the difference between current state and the future state, Rother and Shook (1999).
Examples of parameters that need to be measured to create a correct and valid VSM is downtime, cycle time, lead time and value adding time.

3.6 The product

IMI Hydronic Engineering engineering has a broad range of products while one of the most frequently sold product family is the STAD with approximately 1 million sold valves during the year of 2014. The product acts as a balancing valve used in heating and cooling systems functioning at a maximum temperature of 120 ºC while the minimum working temperature is at -20 ºC. Furthermore the valve is produced in dimension between DN 10-50 (mm), meaning the thread diameter where the pipes connect. Figure 8 shows the product build-up and components it consists of.

The STAD has 5 functions presented by IMI Hydronic Engineering (www.imi-hydronic.com):

- **Balancing** – The valve can be used with IMI Hydronic Engineering balancing methods to obtain a balanced HVAC system
- **Pre-setting** – The valve can be set to a specific Kv value based on th nu,bers shown on the hand wheel with Kv values (or software tools like HySelect)
- **Measuring –** The measuring points allows measuring of differential pressure over the valves as well as temperature of the media. By measuring the differential pressure the flow in the valve can be calculated using the specific Kv value for certain hand wheel setting.
- **Shut-off –** Closing the valve to have no flow through it.
- **Draining –** Drain the media from the system

The valve is along with the spindles die casted of a material called AMETAL, which is a dezincification resistant alloy of IMI Hydronic Engineering (www.imi-hydronic.com) produced by Nordic Brass. Further the valve, as well as other components, is machined in Ljung but the process of assembling the STAD was moved in the year of 2001 from Ljung to Poland because of economic reasons.

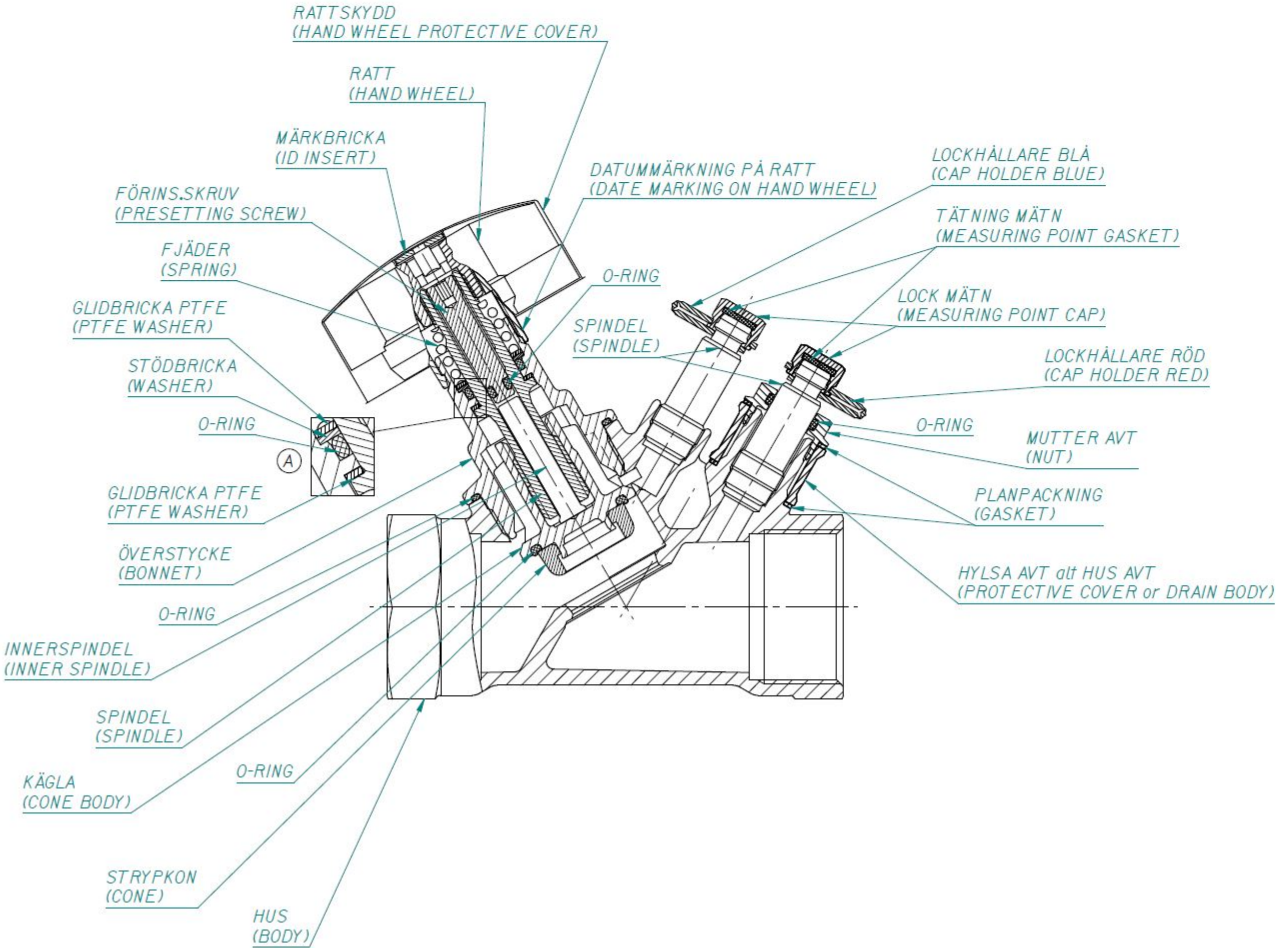


Figure 8 - Product build up

3.7 Bill of material

BOM (Bill of Material) is a listing or description of materials and components a product consists of with the respective quantities required Chang (1997). In the machine tool industry there are two types of BOM called engineering BOM (EBOM) and manufacturing BOM (MBOM).

The designer constructs an EBOM after a product has been designed and is used to describe a product structure as shown in figure 9. Throughout a series of hierarchical subsystems the structure as well as the part list can be defined and functionally form the product according to Chang (1997). The EBOM can later be transformed into the MBOM by considering assembly sequence and constraints.

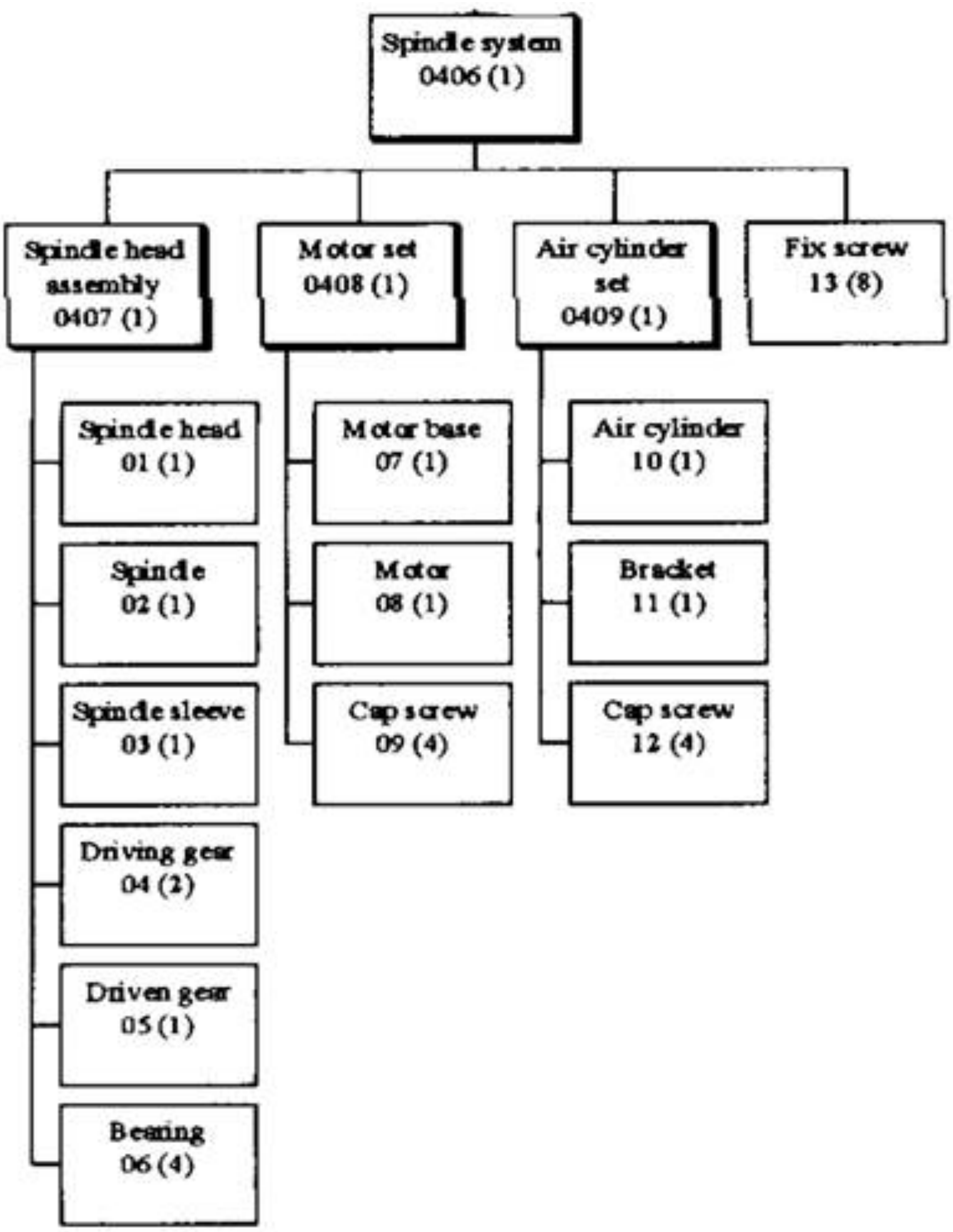


Figure 9 - Example of a BOM of a spindle system, Chang (1997)

4. EMPIRICS

In this chapter the current state along with the improvements will be presented and compared to the theory. This chapter will be the base for discussion of the problems at hand.

4.1 Pre study

Choosing the system that was studied was decided together with the company. The reason behind why it became the assembly of the STAD was that most of the features on the STAD like threading, O-rings, washers and spindles can be found in a lot of other products. Also similar parts can be assumed to exist on future products. Therefore the results of evaluating and applying the Dynamo++ method on the product STAD will give a good foundation for adaptation on other existing products at IMI Hydronic Engineering as well as their future products.

Walking the chosen process itself is a part of the pre study phase when using the Dynamo++ method. This could not be done in this case since the assembly is placed in Poland. Therefore several films a long with data received from Poland has been thoroughly studied in order to get understanding of how the process works today.

4.2 Current state mapping

Value stream mapping, VSM, is a tool used to map current states at companies and is recommended to use by Dynamo++. How ever it is a time consuming, high effort method if it is to be effective. Due to the time plan and wishes of the company it was not possible to do an effective VSM, therefore the current state mapping of this project consisted of analysing films and data collected from Poland in order to get an understanding of the assembly process as it is today.

The station pre-assembly, jolting of cone body, is not included in the Avix-analysis from Poland since it is being done separate from the assembly of the product. Stations included in the analysis are stations 2-4.

Station 2 has a cycle time of 31.7 seconds and consists of only necessary operations. As seen in figure 10 this is the assembly station with the lowest cycle time and it does not depend on the assembly speed of any previous station. This because the cone body part is delivered in large quantities.

Station 3, assembly of body and leakage testing has a theoretical cycle time of 28.12 seconds, however the actual cycle time as seen in the analysis is 36 seconds. This is the result of the operator being unsynchronized with the machines and has to wait for them to finish before starting a new assembly.

The final station, packaging and final assembly has a theoretical cycle time of 31.3 seconds while the actual cycle time is 37.7. The gap between theoretical and actual cycle time here comes from having to wait for a product from the previous station.

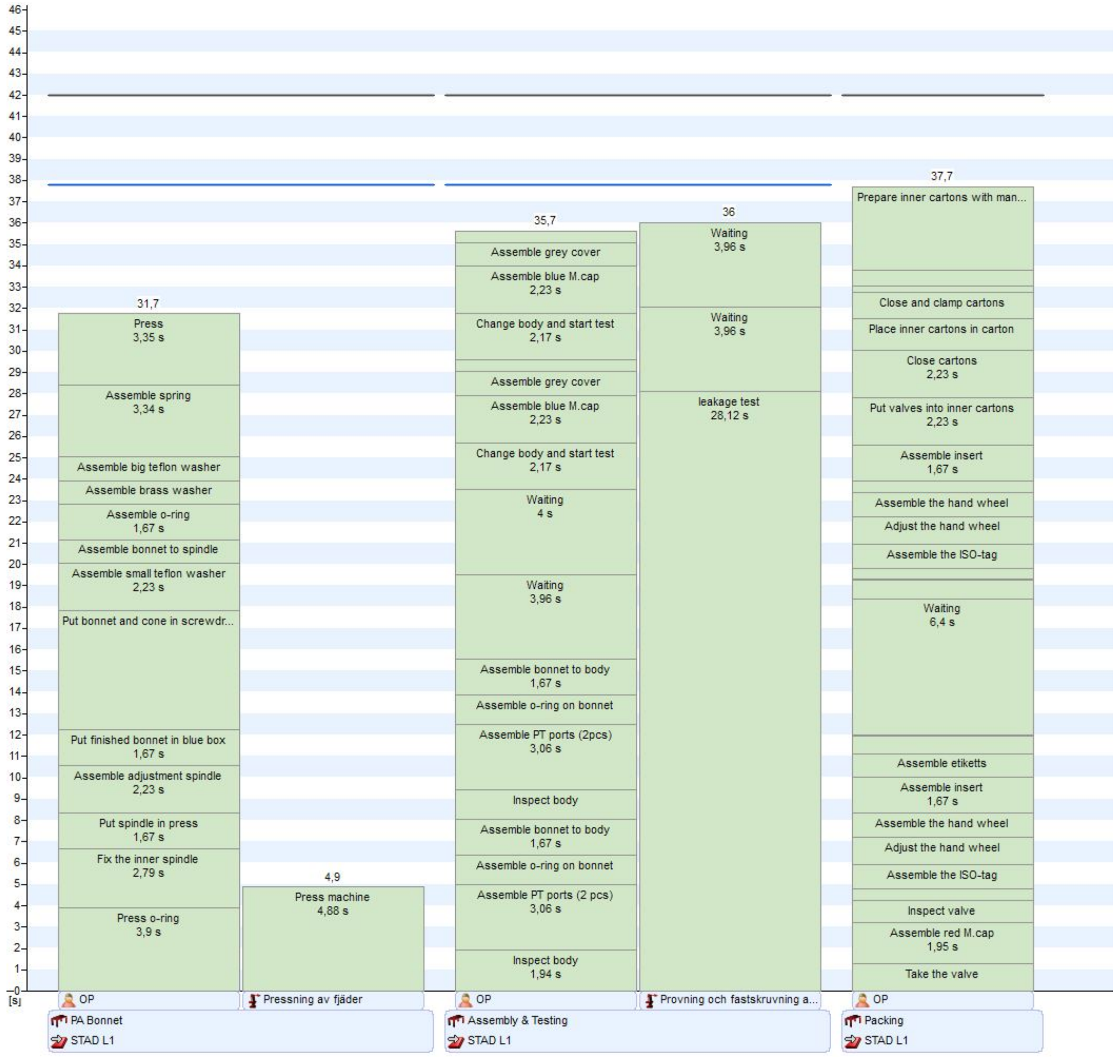


Figure 10 - Avix-analysis of the assembly process

The manufacturing process as it is today consists of four separated assembly lines, which in turn consists of four stations. (1) Pre-assembly, jolting of cone body, (2) assembly of bonnet, (3) assembly of body and (4) final assembly and packaging. This is illustrated in figure 11 below.

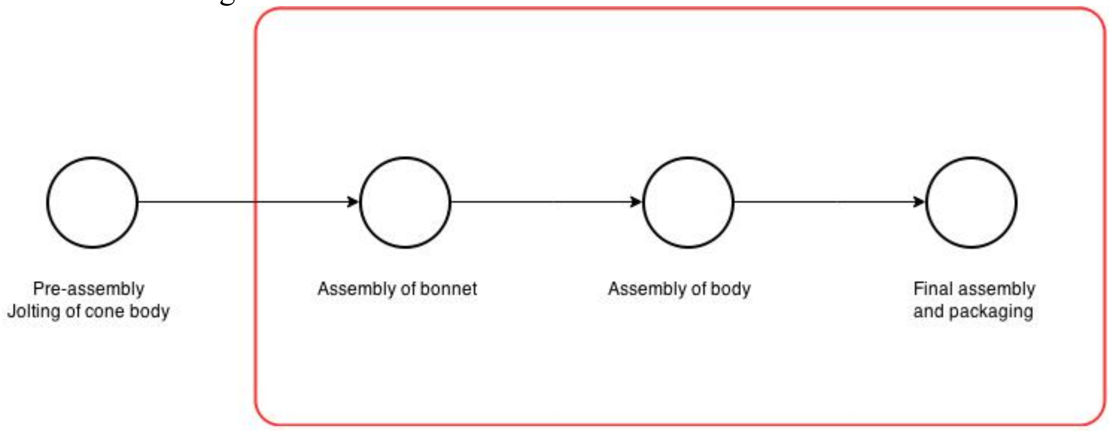


Figure 11 - Map of the assembly process

In order to understand the production flow of the product a brief description of each station will follow.

The first of the four stations is (1) jolting of cone body. The operator here places the cone and body in a fixture and then uses a machine jolting the parts together with an O-ring in the middle. No picture available.

In the second station, (2) assembly of bonnet, an operator assembles the bonnet. Here the operator uses two different fixtures while mounting in total two O-rings on spindles, placing two PTFE washers, a metal washer and a spring in along with the main spindle inside the bonnet and then, with a machine, pressing and fixating the package together. The layout can be seen in figure 12.

Figure 12 - Layout of station 2

The assembled bonnet is then put in a box and transported to the next station, which is (3) assembly of body. Here the bonnet is being mounted together with the body. The operator's work here is to place the bonnet in the house along with the spindle measure points and an O-ring. The STAD is then put into a fixture where a machine is used to tighten the parts together with a predetermined force. Also in station three a leakage test is used to test the quality of the product. This is being done by applying pressure from different directions to the product in order to make sure it is completely water tight. After the product is cleared by the leakage test it is passed manually to station four, (4) final assembly and packaging. The layout of station 3 can be seen in figure 13.

Figure 13 - Layout of station 3

The station, final assembly and packaging consist of mounting the hand wheel along with the ID insert and the product label and pressing it together. Then the final STAD is packed into a carton and is ready for shipment. The layout can be seen in figure 14 and the complete assembly process is illustrated in the HTAs in Appendix B.

Figure 14 - Layout of station 4

4.3 Hierarchical Task Analysis

According to the Dynamo++ method a HTA is needed in order to use as a base for the LoA-analysis. The different HTA's is shown in Appendix B.
Every assembly station has its own HTA-tree and these clearly show every task of the assembly in the order it is being executed. An example one of the HTA-trees is shown in figure 15. As seen in the HTA-tree every task has got its own number that conforms with the LoA-analysis tables and matrixes.

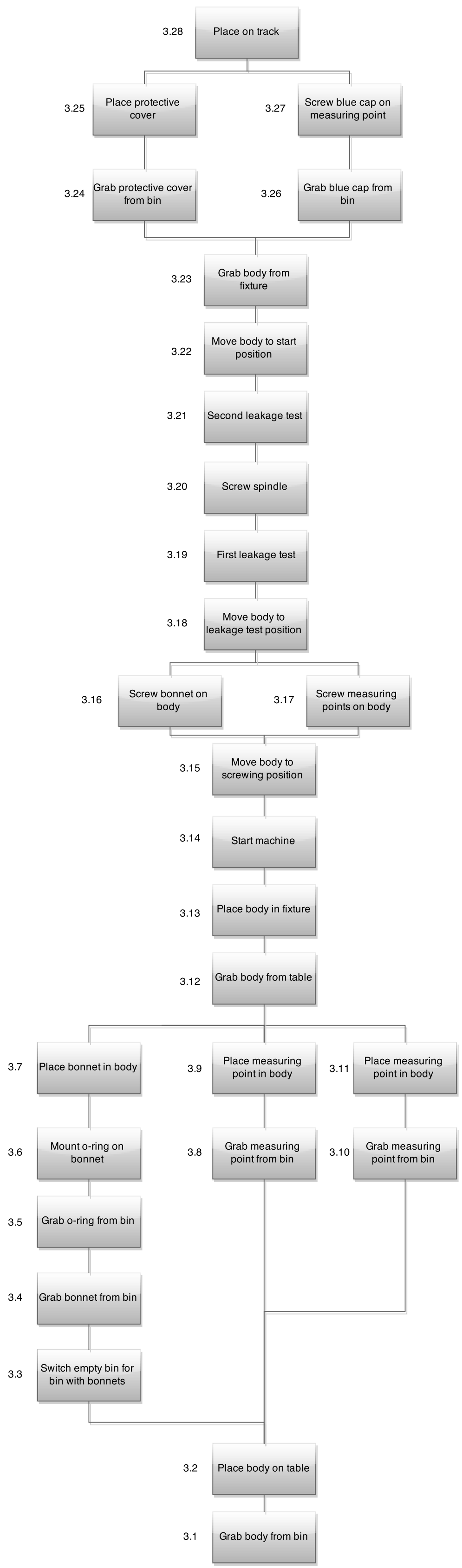


Figure 15 - Example of HTA of station 3

4.4 Levels Of Automation

Every task of the complete assembly was evaluated by using LoA measurement. This gives a good view of every task and how the level of automation in terms of both mechanical and informative is today and what can be improved. Each individual task has its own LoA and is presented in tables in Appendix C.

Furthermore, a compilation of the LoA-analysis of each station was performed in order to get a good overview of the situation as it is. Example of how a LoA matrix can show where the tasks of a station are located in terms of mechanical & cognitive levels of automation is shown in figure 16.

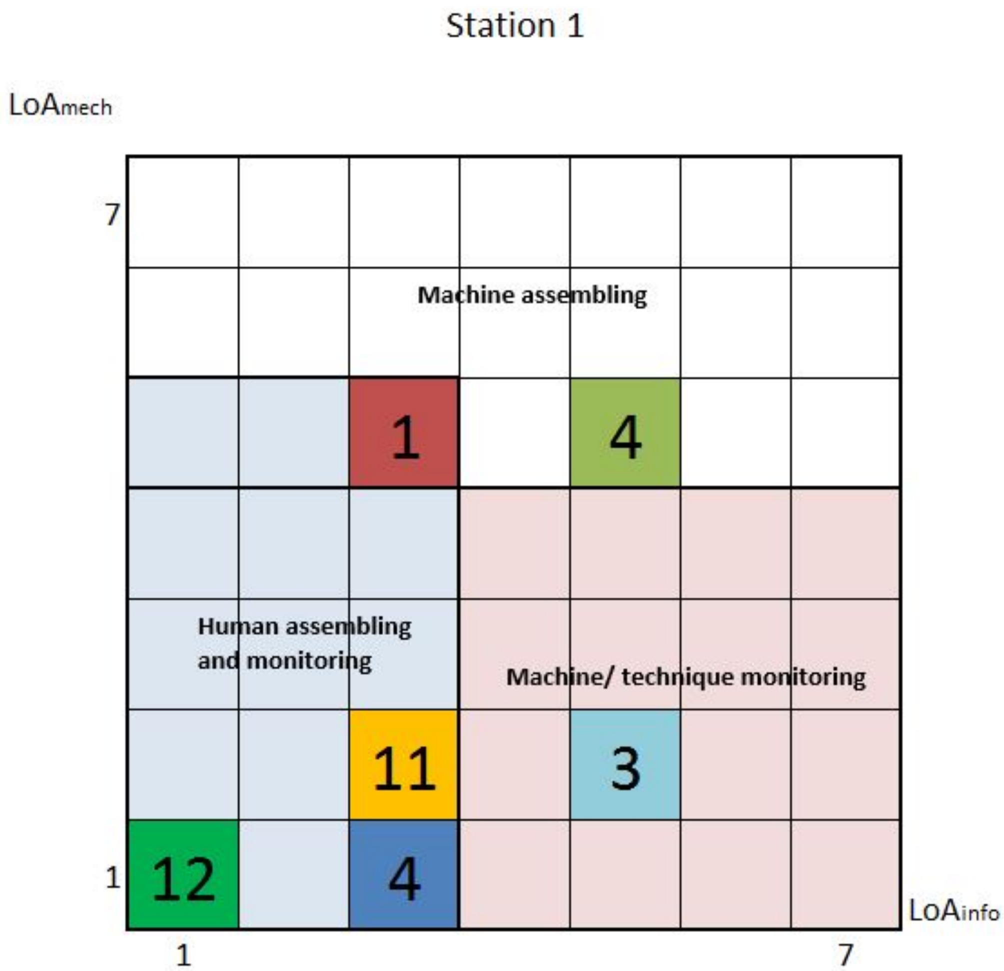


Figure 16 – Example of a station's LoA compiled into one matrix

A complete list of all the LoA-analysis regarding both stations and individual task both in form of tables and matrixes can be found in Appendix D.

4.5 Workshop

A workshop was held at the company where engineers as well as employees with different levels of education from different instances were invited to take part. The goal of this workshop was to highlight problematic areas of the manufacturing process and the product itself as well as brainstorming solutions for these problems.

During the workshop all four of the assembly stations were discussed in chronological order and several suggestions along with solutions regarding problems and improvements came to mind. In addition to finding solutions and improvements the possibilities regarding an increase of LoA, both mechanical and informative, were highlighted and discussed. Here the current state LoA tables (Appendix C) were used as a base for the engineers to discuss the levels of cognitive and mechanical automation within reasonable limit to achieve. The goal when discussing the possibilities regarding the LoA was to get as high increases in the desired parameters while keeping investments like cost and time as low as possible. LoA-analysis results, films and pictures of the assembly as it is today were shown to get the attending engineers and employees in the right mind set and open up for discussion as well as contribute with ideas.

The manufacturing process as it is today was divided into 4 different categories as follows:

- Station 1, pre-assembly, jolting of cone body
- Station 2, assembly of bonnet
- Station 3, assembly of body
- Station 4, final assembly and packaging

Every idea that was generated during the workshop was rated by a point system where each person got three votes that were graded from 1 to 3 to rate their favourite ideas. Here each idea will be presented together with the points it received within the parentheses after the idea itself:

Station 1

- Change of material in the cone and the cone body from AMETAL to some kind of plastic material, such as PEEK plastics, in order to be able to integrate the cone body, O-ring and the cone into one detail instead of three as it is today. This will result in the complete removal of station pre-assembly, jolting of cone body. (4)

Station 2

- Integrating the O-ring, washer and PTFE washer that are placed on the spindle today into one component, for example by finding a material that can be used as the three mentioned components at the same time. (0)
- The use of a sealed ball bearing instead of the O-ring, washer and PTFE washer. This would reduce the number of components with 2. The use of a sealed ball bearing will however result in a more difficult assembly process since it has to be mounted with press fitting. (0)

- Integration of pre-setting screw and inner spindle, this would reduce the number of components as well as reduce one assembly operation. (2)
- Adding a metal bellow that would be mounted on the cone body as well as the inside of the bonnet, which would render the need of all O-rings in the finished bonnet unnecessary. This would also reduce the number of difficult assembly tasks. (4)
- Implement a work order for picking parts. As it is today the different parts are not organized in front of the operator in the order they are to be assembled in and does not follow any logical pattern. By just reorganize the placement of the parts so that they follow the assembly order, the cognitive part of LoA will increase from 1 to 2. (0)

Station 3

- Change of material in the bonnet from AMETAL to some kind of plastic, such as PEEK plastic, this would make it possible to use snap fits or similar fastening methods when mounting the finished bonnet with the body instead of threads as it is today. (1)
- Implement the use of a locking ring when fastening the bonnet into the house. This would remove the threads as it is today. (0)
- Make it possible to use the fixture at task 2.2 instead of 2.13, this would increase the mechanical part of LoA from 1 to 2. (3)
- Move the tasks 2.1-2.13 to station 1 and the tasks 2.23-2.28 to station 3, this would result in the complete removal of station 2. (0)

Station 4

- Change of material in the measure spindle points so that snap fits can be used instead of threading. This would remove the screwing operation as it is today. (0)
- Remove the cap holders completely since they should not be needed. This because the measure points should stop any leakage as they are today, cap holders only exist today to increase safety if they measure points were to fail. Alternatively redesign the measure points to ensure that they will not fail. (0)
- Remove the need for calibration of the hand wheel before mounting it by letting the supplier make sure they are delivered calibrated. (0)
- Remove the ID insert by replacing it with the required text directly printed on the hand wheel. This can be done by for example using a laser printer in the assembly process. (1)
- Combine the track (task 4.1) with fixture instead of taking the product from a track and placing it in a fixture (task 4.2). This removes unnecessary replacement of the product and increases the mechanical part of LoA from 1 to 2. (1)

4.6 Interviews

In order to get a good understanding of the product and what possibilities there are regarding changes, function and requirement specification two interviews have been concluded. The first interview was mainly focused on the function of every part and was concluded in order to get a full understanding of the complete product. This was done by interviewing Leif Marstorp, Development Engineer, who is what the company considers an expert on the STAD. The second interview was done with the Manager of Existing Products, Christofer Sundqvist at IMI Hydronic Engineering in order to generate ideas on possible ways to redesign the product. The interviews can be found in Appendix G.

4.7 Design For Automatic Assembly

It is crucial to optimize a product in the design stage to ease the assembly of it before major investments in tools and robots are made. Therefore an evaluation of the STAD where made thru a DFA2-index to assess how viable the design is for automatic assembly. After identifying all the parts they were separately evaluated through a series of categories presented in figure 17. All the parts then received a total score presenting how suitable it is for automatic assembly. The DFA2-index also presents a percentage on how close the product design is to its ideal solution for automatic assembly and gave the STAD a value of 63.9 % as presented in figure 17.

	Part level																			
List of all parts	Number of identical parts	Need to assemble part?	Level of defects	Orientation	Fragile parts	Hooking	Centre of gravity	Shape	Weight	Length	Gripping	Assembly motions	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Joining	Check/adjust	Sum
Inner Spindle	1	1	9	1	9	9	1	3	9	9	3	9	3	1	3	3	9	9	9	100
Spindle	1	9	9	1	9	9	1	3	9	3	3	9	9	1	9	3	3	3	9	102
O-Ring 4*2	1	9	9	9	9	9	9	9	9	9	1	3	1	1	1	9	9	3	9	118
O-Ring 13,3*2,4	2	9	9	1	9	9	9	9	9	9	1	3	1	1	1	3	9	3	9	104
Bonnet	1	9	9	1	9	9	1	3	9	3	3	9	9	3	3	3	3	3	3	92
Body	1	9	9	1	3	9	3	1	9	3	9	9	9	1	9	3	3	9	3	102
PTFE washer 1	1	9	9	1	9	9	9	9	9	9	1	3	1	1	3	3	9	9	9	112
PTFE washer 2	1	9	9	1	9	9	9	9	9	9	1	3	1	1	3	3	9	9	9	112
Presetting screw	1	9	9	1	9	9	1	3	9	9	9	3	1	1	9	9	3	3	3	100
Washer	1	9	9	1	9	9	9	9	9	9	1	3	1	1	3	3	3	3	9	100
O-Ring 59*2	1	9	9	1	9	9	9	9	9	9	1	3	1	1	3	3	9	9	9	112
Spring	1	9	9	1	9	1	1	3	9	9	3	9	9	1	9	9	3	3	3	100
Cone body	1	9	9	1	3	9	1	1	9	9	9	3	3	3	9	9	3	3	3	96
Cone	1	1	9	1	3	9	1	3	9	9	3	9	9	1	3	9	3	3	9	94
Spindle measure point 1	1	1	9	1	9	9	1	3	9	9	9	1	9	3	9	9	3	3	3	100
Spindle measure point 2	1	9	9	1	9	9	1	3	9	9	9	1	9	3	9	9	3	3	3	108
ID insert	1	1	9	1	9	9	1	1	9	9	1	9	1	1	3	9	9	3	9	94
Capholder with blue and red	2	9	9	1	9	1	3	3	9	9	1	3	1	1	3	9	3	3	3	80
Protective cover	1	9	9	1	9	9	1	3	9	9	9	9	9	3	9	3	3	9	9	122
Product label	1	9	9	1	9	1	3	9	9	9	1	3	1	1	9	3	9	9	9	104
Hand wheel	1	9	9	1	9	9	3	3	9	3	1	9	9	3	9	9	9	9	9	122
Number of parts:	21																		Total Sum:	2174

Assembly index A = 0,639035861 63,90359 %

$$\text{Assembly index A} = \frac{Total\ sum}{Maximum\ points \times number\ of\ parts}$$

Figure 17 - DFA2-index

Furthermore, by analysing the DFA2-index the low score parts was identified as hard to assemble and where prioritized to be eliminated from the new design of the product or be redesigned. As can be viewed in figure 17, the parts that gained the lowest score where the O-rings, measure point caps, cone, cone body, pre-setting screw, inner spindle and also the id-insert. To improve the DFA2-index score the focus was to improve the mentioned parts by integrating them, evaluate the significance of them, choice of material and by implementing chamfers to ease insertions. Furthermore ideas generated from the workshop were used to optimize the product and to redesign it.

Firstly, the cone body consist of a cone, cone body and an O-ring as shown in the BOM in Appendix E, which all are parts that gained a low score from the DFA2-index shown in figure 17. To optimize the cone body it was chosen to integrate all of the parts by moulding it in one piece using PEEK plastic as material. This improvement would mainly reduce the number of parts and therefore ease the assembly process. However, a design change was made to ease the assembly of the cone body and bonnet as well. As shown in the figure 18 the new design of cone body have a shape of a hexagon, which gives more insertion possibilities when assembling the cone body with the bonnet. The reconstruction of the cone body also requires redesign of the bonnet as shown in figure 19. Furthermore, the two designs of the cone body and bonnet can be distinguished where the original design in figure 18 and 19 only have two insertion possibilities whereas the redesign in figure 18 and 19 have six insertion possibilities. Therefore the design change increases the score of the cone body in the DFA2-index as presented in figure 21.

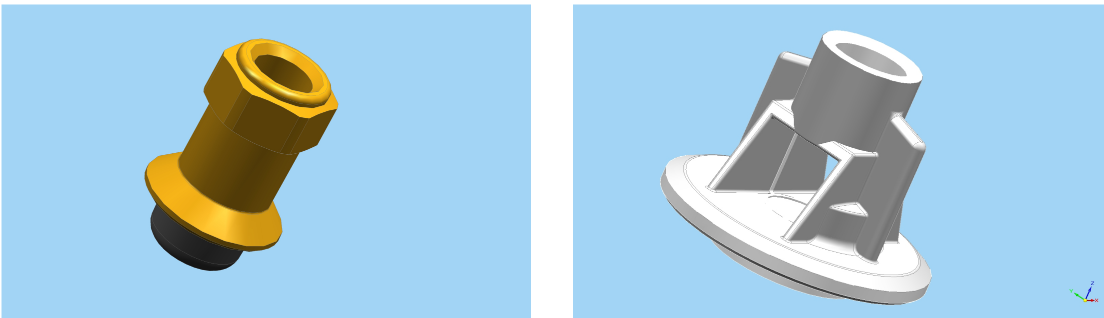


Figure 18 - Redesign of cone body (left figure) compared to its original design (right figure)

Figure 19 - Redesign of bonnet (left figure) compared to its original design (right figure)

The function of the pre-setting screw and the inner spindle is to lock the cone body at a specific flow but still enable the user to close the valve if necessary and the afterward easily find the chosen flow setting. This function was transferred into the hand wheel to eliminate these two parts together with an O-ring, which was designed to seal the pre-setting screw. The pre-setting function being transferred to the hand wheel also makes the id-insert insignificant because of the pre-setting screw being eliminated as shown in figure 20. The main function of the id-insert was to be able to access the pre-setting screw to change its O-ring. This action was possible to do through the hole on the hand wheel show in figure 20. Another function of the part was also to present the name of the product and its dimension. Because of the part being eliminated another marking technique is required and transferred onto the hand wheel.

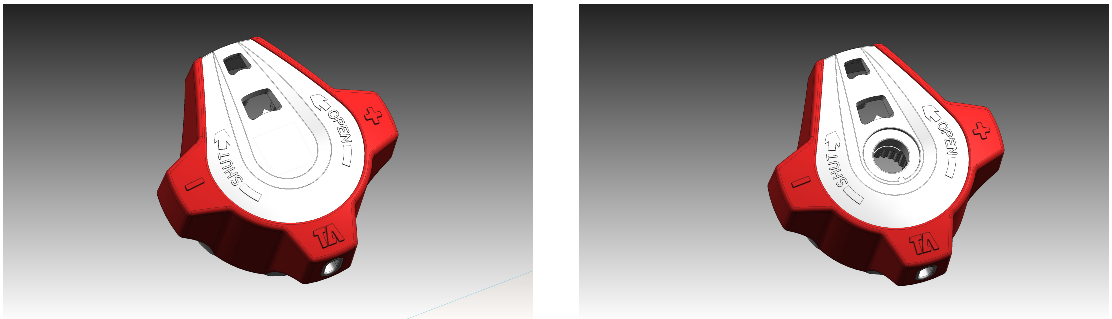


Figure 20 – Redesign of the hand wheel (left figure) compared to its original (right figure)

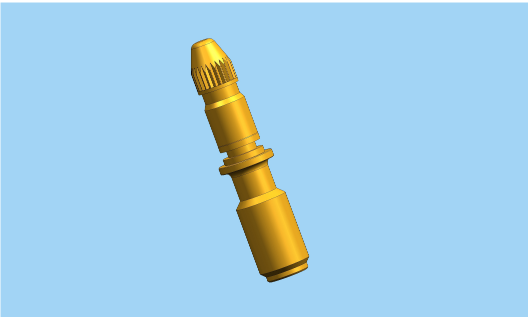
As presented in figure 21 the measure point caps gained the lowest score of 88 caused by its small size and by its fastening method being threads. Therefore the caps were redesigned to be fastened with snap fits instead and being moulded in PEEK plastic. Snap fits being the easiest fastening method in an automatic assembly would increase the scores of the cap holders as shown in figure 21.

	Part level																		
List of all parts	Number of identical parts	Need to assemble part?	Level of defects	Orientation	Fragile parts	Hooking	Centre of gravity	Shape	Weight	Length	Gripping	Assembly motions	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Joining	Check/adjust	Sum
Spindle	1	9	9	1	9	9	1	3	9	3	9	9	9	9	9	3	3	3	9	116
O-Ring 13,3*2,4	1	9	9	1	9	9	9	9	9	9	1	9	9	9	9	9	9	9	9	146
Bonnet	1	9	9	1	9	9	1	3	9	3	9	9	9	9	9	3	3	3	9	116
Body	1	9	9	1	3	9	3	1	9	3	9	1	9	9	9	3	9	9	3	108
PTFE washer 1	1	9	9	1	9	9	9	9	9	9	1	9	9	9	9	3	9	9	9	140
Cone body	1	9	9	1	3	9	1	3	9	9	9	3	9	3	9	9	3	3	9	110
Spindle measure point 1	1	1	9	1	9	9	1	3	9	9	9	1	9	3	9	9	3	3	3	100
Spindle measure point 2	1	9	9	1	9	9	1	3	9	9	9	1	9	3	9	9	3	3	3	108
O-Ring 59*2	1	9	9	1	9	9	9	9	9	3	1	9	9	1	9	3	9	9	9	126
Capholder with blue and red	2	9	9	1	9	1	3	3	9	9	1	1	9	9	9	9	9	9	9	118
Protective cover	1	9	9	1	9	9	1	3	9	9	9	9	9	3	9	9	9	9	9	134
Hand Wheel	1	9	9	1	9	9	3	3	9	3	1	9	9	9	9	9	9	9	9	128
Spring	1	9	9	1	9	1	1	3	9	9	3	9	9	9	9	9	3	3	3	108
Number of parts:	13																		Total Sum:	1558
																			Assembly index A =	0,739791073 73,97911 %

Assembly index A = $\frac{Total\ sum}{Maximum\ points \times number\ of\ parts}$

Figure 21 - DFA-index on new STAD

To ease the task of insertion when assembling the product chamfers was designed on the head of the spindle as shown in figure 22, which would ease the assembly of the bonnet, washer and O-ring. This chamfer therefore gave these parts a higher score in the category of insertion (figure 21) compared to the first DFA-index (figure 17). By adding a track for the O-ring in the redesign also made it possible to eliminate the metal washer located between the PTFE washer and the spring. The main function of the metal washer was to act as a hard surface so the spring would not press on to the PTFE washer and O-ring that consist of a softer material. When the O-ring is located in a track the PTFE washer will align to the surface of the bonnet, which act as a hard surface and becomes a substitute to the metal washer.



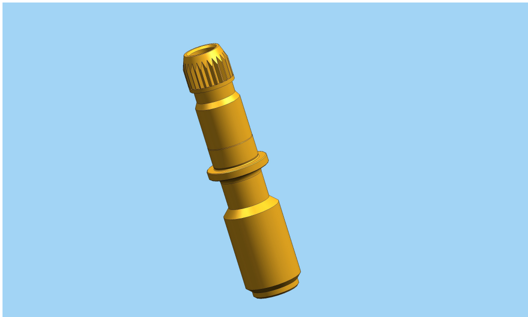
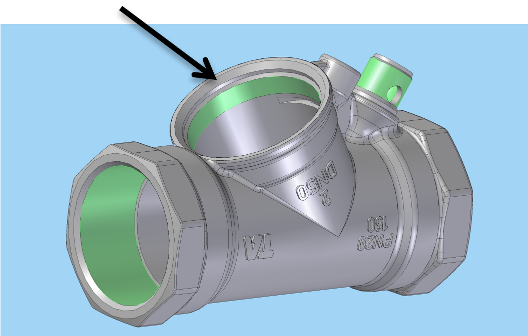


Figure 22 - Redesign of spindle (left figure) compared to its original (right figure)

Eventually a chamfer was also designed on the body (figure 23) to facilitate the task to insert the bonnet. The body therefore also receives a higher score in the category of insertion.



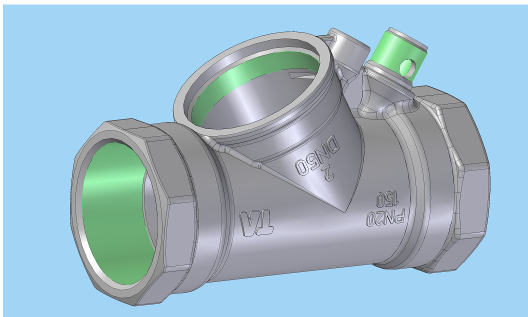


Figure 23 - Redesign of body (left figure) compared to its original (right figure)

After the suggested redesigns on the STAD were followed through a new evaluation of the product was made with the result presented in figure 21. The DFA-index on the new design shows a 10-point increase in automatic assembly suitability. In the BOM of the new product (Appendix E) it can be viewed that the number of parts was reduced by seven, which simplifies the product as well as the assembly process.

5. DISCUSSION

In this chapter the topics from the empirics will be discussed and evaluated to give a broader perspective as well as a better understanding of the accomplished results. The method used to achieve the results will also be discussed.

5.1 Pre study

The choice of system to carry out a study on was a rather obvious with the arguments that the STAD is a long lasting product with features typical to other products of IMI Hydronic Engineering. With confidence from the company it was in the best interest, for both parties, to study the STAD for relevant results and solutions that can be used on future products. This meant that information on the product and its assembly required communication with engineers stationed in Poland. Throughout the whole project the lead time to possess needed information was longer than expected which limited the project, time wise, even more than planned.

The main pre study on the product was through films sent from Poland. The reason behind this is because the assembly of the STAD was moved from Ljung to Poland in the year of 2001. When analysing the process of the STAD some complications was brought whereas the assembly of it never could be observed in real time only by the films. It became difficult to observe the assembly line as a whole line, which limited the understanding of the functionality of the line. Nevertheless, the films gave an excellent perspective on tasks being executed in each station and simplified the process when conducting a hierarchical task analysis. Therefore it can be reviewed that even though, step two in the Dynamo++ method was not carried out the traditional way, required information was received throughout the films to be able to proceed with the method.

5.2 Current state mapping

Current state mapping in this project resemble the value stream mapping in the Dynamo++ method. Because of VSM being a time consuming process and the time limitation of this project a VSM was not carried out. Instead important information was gathered from documents sent from Poland as well as the films of the assembly were used as a basis to map the current state of the STAD. Cycle time and time parameters was gathered from Avix-analysis also sent from personal in Poland.

5.3 Pre-assembly

Station one, jolting of cone body, is a pre-assembly station as shown in figure 11, as well as the measure point spindles also are pre-assembled but is not taken in count in this project. The reason behind this is that the pre-assembly of the measure point spindles is already automatic and therefore it was chosen to rather focus only on the jolting sequence and to improve its process. Another reason is also that the same measure point spindles are used in other products which makes the part sensitive of change.

5.4 Time and flow parameters

Throughout figure 10 it can be viewed that the cycle time of the assembly line is 37.7 seconds and is determined by station four. The cause of this is that the leakage test in station three act as a bottle neck operation and generates the waiting time in station four as shown in figure 10. Even though the leakage test is not actually presented as a bottleneck operation in the Avix-analysis, the films show otherwise. The Avix analyse is not giving a fair representation of the actual assembly process because according to the analysis of the films it is clear that the leakage test generates more waiting time than presented in the Avix analysis. Therefore it was crucial to not only rely on the Avix study but also perform a minor case study on the films to discover flaws in the process. Throughout the minor case study it was discovered that the leakage test is the bottleneck operation causing wait time for both station three and four.

Because the leakage test generates waiting time for the operator in station three while station two have a shorter cycle time the assembly line becomes unbalanced. The result of this is that station two is over producing bonnets whereas station three and four is containing waiting time that can be seen as loses in the assembly. Therefore it is recommended to the second part of the project to analyse the time and flow parameters of the assembly line and balance the assembly line to gain an even cycle time for all the stations. The expectations of these changes would be to reduce waiting time and other loses of the assembly line.

5.5 Hierarchical Task Analysis

The DFA led to a reduction of nine parts in the product structure. These parts are responsible for 29 tasks in the HTAs. It can therefore be assumed that these tasks are eliminated together with the corresponding components. To get a full view of these changes along with the new assembly process for the product chapter four of report two is recommended.

5.6 Levels of Automation

The task presented in the HTAs (see Appendix B) was evaluated to determine its Level of Automation. It can be seen in Appendix D that the majority of the task gains a mechanical LoA of two or less and a cognitive LoA of three or less. Therefore the assembly of the STAD is regarded as manual although with a few automatic operations.

The cognitive LoA is determined to the level of three on the majority of the tasks because of existing assembly instructions at each station. However, it can be questioned if these instructions actually contributes to the cognitive automation since they are barely used during the assembly process and instead acts as decoration. Therefore it is questionable if the presented tasks actually can be qualified as a cognitive automation of level three. Although the instructions do exist which according to the measure system of LoA puts the cognitive level at a three and the issue is instead about how the instructions should be used. It is therefore important to evaluate and change the usage of the instructions to reach full effect of the cognitive automation of level three.

5.7 Workshop

Main purpose of the workshop was to generate ideas to optimize the product as well as the assembly process of it. Although, as this project focuses mainly on the ideas of how to optimize the product to ease the assembly process, most of the ideas affecting DFA was about changing material and integration of components with the collective goal to reduce number of parts.

It was chosen to invite engineers and employees from several departments to get different views on the problems. It is crucial to involve as many types of engineers or employees as possible to get professional perspective within several areas such as quality, construction and production. Without this diversity of experience it is easy to overlook promising solutions. This also improves the communication between departments, which is important to achieve as good result as possible.

The execution of the workshop started with a short presentation about Levels of Automation as well as Design for Assembly and the current state of the STAD. The workshop then proceeded with brainstorming solutions and ideas, which every participant then scored. The participants received three votes that was graded with points from one to three to vote with on the ideas each of them valued as most promising. The problem with this point system was that good ideas were neglected because of limited amount of votes per participant. Instead the point system could rather have been constructed so that every idea would be rated individually on a scale of zero to three. This way every idea would have been evaluated and taken into account. Therefore even low scored ideas were taken considered when redesigning the product.

During the workshop all ideas were gathered and evaluated equally without categorizing in any way. What could have been done instead was to create categories based on the type of idea. As an example, the workshop held at IMI Engineering resulted in ideas that could have been divided into two different categories. The first would be ideas that could be implemented in the current process within a reasonable timeframe e.g. implementing chamfers on the spindle. The second category would be ideas that are better suited to be long term projects that possibly could take several years to implement e.g. implementing a metal bellow in order to seal the product and remove several parts.

5.8 DFA2 - Index

To evaluate the STAD product the tool DFA2-Index was used. It consists of a series of categories scoring (Appendix A) each part on how well it is design for automatic assembly. Throughout the index it is easy to identify parts in need of improvement being the ones with lowest total score. Besides showing the parts total score it also shows more specifically what part of the detail that can be improved. Another advantage with this method is that it can be used in early design stages, even without a physical prototype, which saves time and resources when developing a new product.

However, when applying this tool it is important to be objective about the features that is to be evaluated otherwise it will not have the intended effect. If the parts is scored higher than what they are supposed it will give a misguided result and state that the product is better than what it actually is.
This tool, DFA2-index, does not take into account the effect of reducing the number of parts, although it shows what parts that potentially could be removed. There is a compliment to this tool that can be used for such an evaluation, which has more focus on the product in its entirety instead of each individual part. This tool, called DFA2-index Part level and also created by Stephen Eskilander (2001), is recommended to use. Although, due to its complexity and lack of time it was excluded from this project.

5.9 Design for Assembly

By optimizing a product throughout reducing number of parts and by adding features such as chamfers, its assembly will be easier. Therefore it is important to, if possible, perform a DFA study before investing in expansive machinery and robots. It is also important to perform this study in the early stages of the development of a product due to the fact that it is too late to change product design when assembly equipment is purchased which is a common problem at IMI Hydronic Engineering. Cycle time and number of tasks that needs to be performed in order to have an assembled product will also be reduced when optimizing a product for assembly.

Problems occurring in this case, when performing a DFA study on an existing product, are that changes in design often affected the functionality of the product. It was therefore important when analysing change of material that the new material meets for an example temperature specifications that the product need to full fill as well as other functions such as sealing where needed. The function of sealing can be divided into two categories, static and dynamic sealing. Static sealing meaning that the parts aligning is never moving during usage and dynamic meaning the parts which seal will move during usage. The difference with the two types is that different kind of material for sealing can be used. Dynamic sealing requires a softer material such as O-rings that is able to deform while static sealing can be accomplished with metal surfaces. Metal sealing is most desired from an assembly perspective because no extra part like washers or O-rings are needed, the sealing function can be achieved with the metal surfaces of two parts. Metal sealing would be the optimal if only static sealing is needed because of O-rings and washer are hard to assemble. Though this case regarding the STAD, only O-rings are used as sealing material even on surfaces where static sealing appears and it would be recommended to separate the two sealing types for a more assembly friendly design.

Integration of the cone and the cone body and still keeping the same dynamic sealing function is difficult without having to change the material, however with the change of material as it is suggested here, it is possible to integrate both parts into one. This enables the part to be molded as one piece in PEEK plastic. The plastic should be soft enough to work as a dynamic sealing as well, which means the O-ring could be completely removed from the product. If however, the plastic is not enough to work as sealing material it is possible to use a method called double molding, this means that the O-ring can be molded into the design and delivered as one piece from the supplier.

Together with the change of the material and redesign of the cone and cone body another change has been implemented. This is that the top of the cone body, the one fitting into the bonnet, is made in the shape of a hexagon in order to increase the insertion possibilities, which will ease the assembly process.

The process of changing the cone and cone body this much is a complex process. The new material has to be tested rigorously during long periods. In theory a design like this could work just as well as the design today, however without the above-mentioned testing there is no complete answer. Although it is recommended to test materials like this in order to be able to make more parts out of plastics since it opens up possibilities for snap-fits all over the product.

As previously stated snap-fits are to be aimed at where it is possible, therefore has the cap holders been redesigned to have a snap-fit function instead of threads. This should be an easy change to implement since they only exist for extra safety today, if the measure spindles were to break down and water started flowing out. However, in theory the measure point spindles should not be able to leak since they are designed to seal by themselves. Although to keep the extra safety the suggestion is to design the cap holders from a material and in a way so they still will work as the previous threaded cap holders.

The integration of the inner spindle, pre-setting screw and the O-ring into the hand wheel is a major change of the product, although an important one. It reduces the assembly process with a number of tasks as well as lower the number of parts in the product by four. The idea here is to redesign the hand wheel and ad a pre-setting function directly into the hand wheel. How to do this has not been researched thoroughly enough in this project since it most likely will be a very complex solution and it has to be delivered from the supplier ready for mounting. However there are some ideas on how to solve the problem where the most promising one is a construction made out of unsymmetrical gears. The hand wheel has to have the same type of function as before meaning, it has to be possible to lock the valve from being opened during use while at the same time allowing the valve to be closed in case of an emergency. Another upside of integrating the pre-setting function into the hand wheel is that the possibility of removing pre-setting screws in other products and using the same hand wheel instead increases.

The product contains two spindle measure points as shown in figure 8, these are threaded into the body. When these were evaluated with the help of DFA2-index it was shown that one of these measure points could be integrated with the body already in the manufacture process. This because, according to the “Need to assemble parts?” (Appendix A) category got a score of 1. The second spindle could not be integrated since it has to be able to unscrew during normal use of the product when using the draining function (it is possible to open a draining valve when the product is in use).

In theory, the second measure point spindle could be integrated as well by redesigning the draining valve in a different way or simply moving it to another part of the product. However this is a major change of the product and requires extensive testing in order to keep the same functionality and has therefore been discarded.

A chamfer were created on the spindle in order to ease the insertion of the bonnet on top of the spindle as well as for the insertion of the O-ring and PTFE washer. This chamfer was placed on top of the spindle as seen in figure 22 and affected several insertion operations. This shows that it is possible to facilitate several operations with one minor change of a part, which is something that a construction engineer should strive for.

The insertion of the bonnet into the body was also simplified by using a chamfer before the bonnet reaches the threads. This lowers the risk of the threads being damaged during the insertion process.

The two above named parts was provided with chamfers because it is two major parts in the complete product and affects many operations, however chamfers is a design feature that should be implemented on as many parts used for or in an insertion process as possible. It is a fairly easy way to simplify an assembly process. It will also protect threads or edges from getting damaged or destroyed. Since chamfers helps with the insertion of parts less precision is needed for the insertion process. This will open up possibilities for a broader range of machines or tools used for the assembly process, both automatic and manual.

5.10 Interviews

The interviews performed in this study were used in order to help generate ideas on how to change the product in a way so that the function would still remain the same. For example, Leif Marstorp suggested creating a track on the spindle in order to be able to mount the O-ring on the spindle instead of inside the bonnet. This resulted in that the metal washer in the upper part of the body simply could be removed. The interview with Christoffer Sundqvist resulted among many things in further devolving the idea of making the cone and cone body in a plastic material in order to reduce the number of parts and simplify the assembly process.

Both of the interviews were also used to discuss the ideas generated using the DFA tool and verify that the ideas are theoretically possible.

During the interview it also came up that as it is today no type of DFA-method is applied when creating new products. There also is no method for looking at automation and the possibilities of automating a process. Therefore it is recommended that a method, like the one used in this project is adopted and implemented in new projects. This will result in a product better suited for automatic assembly.

5.11 Validity and reliability

The validity is supported by the fact that every result and redesign has been checked against the theory behind the decisions as well as expert engineers at the company IMI Hydronic Engineering. However, even if the results will theoretically work there has been no actual testing of the redesigned product and it is therefore impossible to say with absolute certainty that it will work as intended. This means in order to absolutely validate the results in this thesis further testing has to be done.

6. CONCLUSION

In this chapter the project questions will be answered on the basis of the theory, empirics and discussion. The project questions will be presented as bold followed with its answer in the text body.

Is there an applicable method for this project regarding automatic assembly ready for use?

No method that was fully applicable on the issue of this project was found, but the DYNAMO++ method was used as a base for approaching the problem. Although, due to time constraints the current state mapping was made throughout films and documents instead of performing a value stream mapping.

If not, how will it be adjusted to suit this product and process?

The changes made on the DYNAMO++ method to suit the product were to perform a DFA to make the assembly of it easier. Therefore the product was optimized for automatic assembly before any case studies was performed on the assembly processes as well as on needed equipment.

Is it possible to use this method for future products and designs at IMI Hydronic Engineering?

The method used on the product can be used on future products and it is recommended to apply it in the early design stages rather than as in this case on an existing product.

What problems with design and construction will appear when implementing the chosen method on the product STAD DN 50?

The main problem with design changes on the product is that it requires testing with long lead times to ensure that the product meets required specifications. The tests are very important when considering material change.

What changes can be done to the product with design for assembly in mind?

Smaller design changes were made throughout adding chamfers to ease insertion and the assembly of some parts. Furthermore, several changes in form of integration of parts were made which resulted in a reduction by nine parts. Though, the integration of the cone body also required material change to function properly.

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Appendix A - DFA2 - Index, tables of evaluation for each category

The method DFA2-index along with the tables used in this appendix is created and designed by Stephen Eskilander (2001) and this is a compilation and explanation of his method.

Need to assemble part?

It is important when designing or redesigning a product to strive for integrating and/or remove parts in the product. There are three questions that can be answered in order to confirm if the part is needed or can be removed:

- Does the part have to move compared to other parts when the finished product is in use?
- Does the part have to be of different material than connecting or already assembled parts?
- Does the assembly process dictate that the part has to be separate because otherwise assembly is impossible?

Need to assemble parts? The questions described above have to be answered for evaluation. A part that does not perform a relative motion has to be of another material or must be separated in order for assembly/disassembly reasons to be eliminated or integrated.	
The part has reasons for being separate (at least one ”yes” to the three questions)	9 points
The part should be eliminated/integrated (all three questions answered with ”no”) but the part is still a separate part in the product.	1 point

Level of defects

In order to avoid unscheduled stops it is important to have a high quality of parts and avoid misshaped or otherwise damaged parts that can cause a stop.
The level of defects should be less than 1 out of 1000.

Level of defects of parts that are to be assembled. Geometric defects that might cause unscheduled stops in an automatic assembly system should be avoided, or parts with functional defects.	
P < 0,1 %	9 points
0,1 % ≤ P ≤ 1,5 %	3 points
P > 1,5 %	1 point

Orientation

The need for re-orient a part after delivery should be as little as possible. One way of solving this problem is to have the supplier deliver the parts already oriented in for example a fixture.

Orientation. If a part could be delivered oriented, cost and uncertainty in the process would be eliminated.	
No need for re-orientation of the part	9 points
Part is partly orientated, but needs final orientation	3 points
Part orientation needs to be re-created.	1 points

Non-fragile parts

In automated assembly system feeders is often used as a way to feed and orient a part to its corresponding machine. In order to be able to use feeders the parts in question has to be non-fragile to avoid unscheduled stops.

Feeding often requires **non-fragile parts**	
Part is not fragile	9 points
Part can be scratched, which is not acceptable.	3 points
Parts can not fall without deforming	1 point

Hooking

Parts should be designed so that hooking or tangling is impossible when using for example a feeder or delivery in bulk. One way of doing this is to make the design so that hooking and tangling is impossible.

State during feeding, hooking: There should be no risk of parts hooking into each other for example in a bulk vibration feeder.	
Parts cannot hook to each other and tangle up.	9 points
Parts can hook to each other and tangle up.	1 point

Centre of gravity

The centre of gravity of a part is important to consider since it is one the most used methods when separating and sorting parts in feeders. The centre of gravity should give the part a stable state of rest while also placing the part in a special position. To test this the part can be dropped repeatedly on a table and observe how well the part places it self.

Centre of gravity for the part should be positioned for use in feeding. Drop the part repeatedly on a table to determine its state of rest. Simple orientation often means reliable and cost effective feeding.	
Part has a stable state of rest and orients itself with correct side upwards.	9 points
Part has a stable state of rest, but orients itself with wrong side upwards.	3 points
Part has an unstable state of rest and orients itself with different sides upwards.	1 point

Shape

The shape of a part can make it both easier as well as harder to orient and insert into an assembly. Therefor it is important to design parts so that they can be inserted in as many different positions as possible while still be assembled in the correct way.
The symmetries of a part can be divided in two different classes, alfa- and beta-symmetry. Figure 24 shows, in a simple way, the differences between the two classes as well as helps scoring the part in question for the DFA2-index.

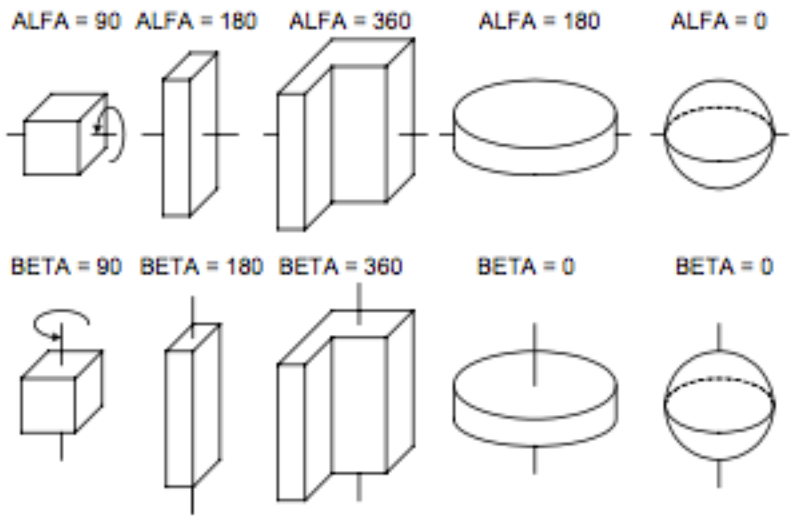


Figure 24 - Example of alfa- and beta-symmetries and the score of different shapes.

Shape of a part is the sum of α- and β-symmetry. Symmetrical parts decrease the need for unique orientation.	
$\alpha + \beta < 360$	9 points
$360 \leq \alpha + \beta < 540$	3 points
$540 \leq \alpha + \beta \leq 720$	1 point

Weight

Minimize the weight of a product is recommended since lower weight often result in less expensive assembly equipment.

Weight, of the part. This affects the choice of equipment.	
0,1 g ≤ G ≤ 2 kg	9 points
0,01 g ≤ G < 0,1 g or 2 kg < G ≤ 6 kg	3 points
G < 0,01 g or G > 6 kg	1 point

Length

The length of a part effects the size of grippers, feeders etc as well as the size of robot cells and machines used for assembly. Therefor it is important to optimize it as much as possible. While its important not to have parts that are to large or long it is also important to not design parts to small.

Length. The length of a part is the longest side of an enclosing prism. This affects the choice of equipment.	
5 mm ≤ L ≤ 50 mm	9 points
2 mm ≤ L < 5 mm or 50 mm < L ≤ 200 mm	3 points
L < 2 mm or L > 200 mm	1 point

Gripping

Grippers are usually designed for gripping a specific and single part and are often expensive. When designing a product it is therefore important to have as a goal to create gripping surfaces so that one gripper can be used for multiple parts. The surfaces for gripping should also be possible to use when mounting the part in its final place.

Gripping is simplified if there are defined surfaces with determined geometry for use. Soft parts, e.g. plastics and rubber, are difficult to grip with a mechanical gripper since the parts can deform from the forces in the gripper.	
Part has surfaces for gripping and can be gripped with the same gripper as the previous part.	9 points
Part has surfaces for gripping, but requires a new, unique gripper that could not be used for the previous part. Part has surfaces for gripping and can use the same gripper as used earlier, but not for the previous part.	3 points
Part has no surfaces for gripping or is flexible.	1 point

Assembly motions

The assembly motion should be as simple as possible and can be compared to a human assembling a part with only one hand. Pushing a part in place is considered to be the easiest way to assemble and should be preferred. Having to use a twisting motion or multiple moving parts should be avoided.

Assembly motions (during insertion) will be faster, the simpler they are.	
Assembly motion consists of a pressing motion with one part being assembled to already assembled parts.	9 points
Assembly motion consists of further motions than pressing motion with one part.	3 points
Assembly motion is an operation with multiple movable parts that simultaneously are assembled to already assembled parts with other motions than pressing motion.	1 point

Reachability

It is important to create space for gripping tools and special tools like screwdrivers. There should not exist any obstacles for insertion for the part nor the tool used for insertion.

Reachability for assembly operation should not be limited. All parts should be inserted in the same direction.	
No restrictions or problems for reaching when fitting the part.	9 points
Reachability is limited. Other assembly direction than previous part.	3 points
Reachability is limited and requires special tools or grippers to perform the assembly operation. Other assembly direction than previous part.	1 point

Insertion

In a well-designed product there is no obstacles when inserting parts during the assembly process as well as not having to assemble more than one part at a time. When using fastening methods like threading it is recommended that chamfers be used to avoid the destruction of the threads.
When fitting parts together round holes should be used since it is easier to fit a round shape rather than a non-round object. An example of chamfers is shown in figure 25.

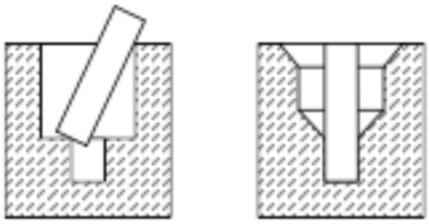


Figure 25 - Chamfers used for insertion

Insertion is simplified if there are chamfers or other guiding surfaces, e.g. an edge that can be used as a mechanical guide for the fitting operation, in the part.	
Chamfers exist to simplify the insertion operation.	9 points
No chamfers, but other guiding surfaces simplifies the insertion operation.	3 points
No chamfers or other guiding surfaces.	1 point

Tolerances

When it is possible it is recommended to use as high tolerances as possible while maintaining full functionality.

Tolerances for insertion operations, for example the distance between a peg and a hole during insertion or whenever there is manipulation of parts relative to each other. Too small tolerances increases the risk of failure during insertion and the system could stop.	
Tolerance > 0,5 mm	9 points
0,1 mm ≤ Tolerance ≤ 0,5 mm	3 points
Tolerance < 0,1 mm	1 point

Holding assembled parts

When a part is put in place it should be kept in place without any assistance from external tools. Having to use external temporary tools to help with assembly is expensive and can very often be avoided by design of the product.

Holding assembled parts is necessary if parts cannot keep orientation and position after assembly. Parts that are secured immediately, i.e. does not lose orientation or position if the assembly is turned up side down, ensures a more reliable assembly process.	
Part is secured immediately at insertion.	9 points
Part keeps orientation and position, but is not secured.	3 points
Part must be held after insertion to keep orientation and position.	1 point

Fastening method

When designing fastening methods in a product it is important to always aim at having as few fastening operations as possible. Using a base object as a fixture that keeps assembled parts in place during assembly and then is mounted together with a single motion can do this. Furthermore the aim when choosing fastening methods should be snap fits since it is a single, simple pressing motion.

Fastening method. How is the analysed part itself fastened?	
No fastening method at all (the part is placed on or in an already assembled part), or only snap fits.	9 points
Screwing- or pressing operations.	3 points
Adhesive fastening methods, welding, soldering, riveting	1 point

Joining

As mentioned in the previous category snap fits should be the aim when designing fastening methods. As a result of using snap fits or simple pressing motions extra equipment, such as screwdrivers, for fastening can usually be avoided.

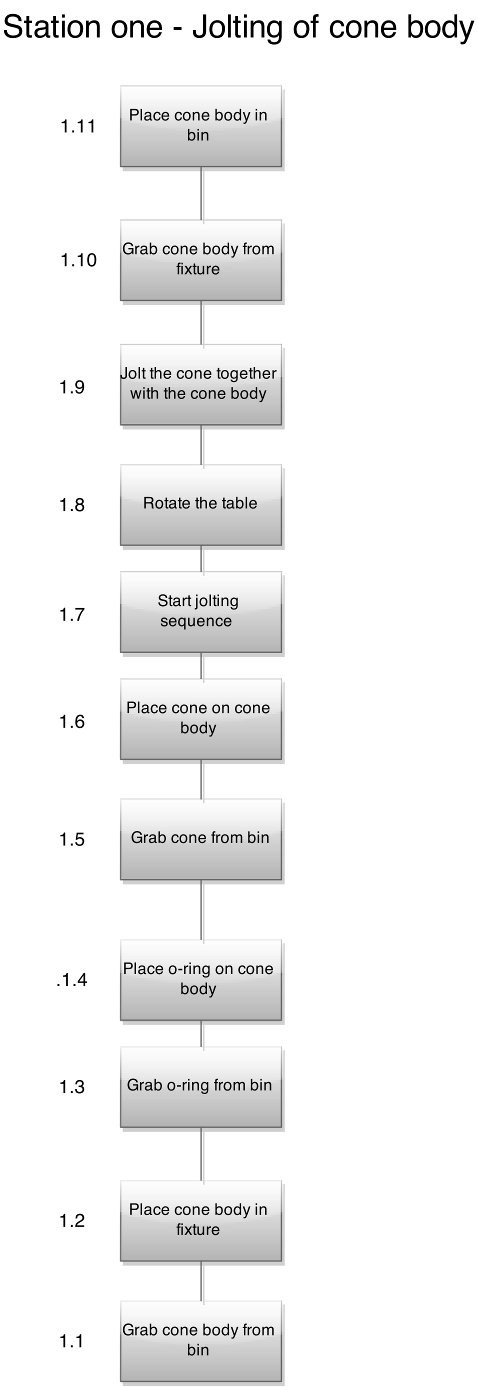
Joining: Extra equipment or tools (e.g. press tools or screwdrivers) should not be needed to fit the part into place.	
No extra equipment is needed.	9 points
Extra equipment or tools are needed to fit the part in place and the extra operation is performed in assembly direction.	3 points
Extra equipment or tools are needed to fit the part in place and the extra operation is not performed in assembly direction.	1 point

Check/adjust

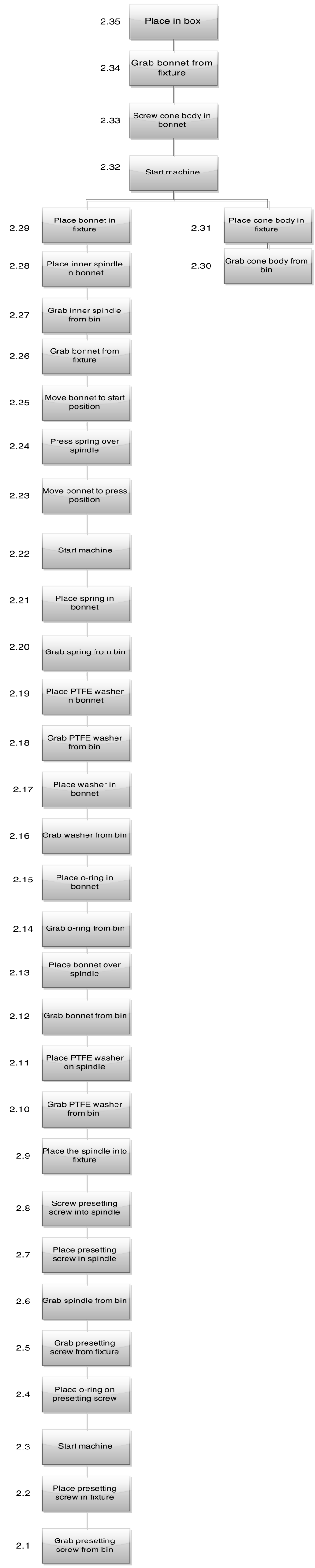
It should not be possible to assemble a product in more than one way since this increases the need for checking if a part is in its right place. If the part is assembled in the wrong way it should be clearly visible without any type of testing.

Check/adjust is not needed if the product is designed according to "poka yoke", i.e. it is impossible to assemble the part in more than one way. Every extra operation for checking or adjusting is extra work and a symptom of a design that is not quite satisfactory.	
Unnecessary to check if part is in place.	9 points
Necessary to check if part is in place or assembled correctly.	3 points
Necessary to adjust or re-orient part.	1 point

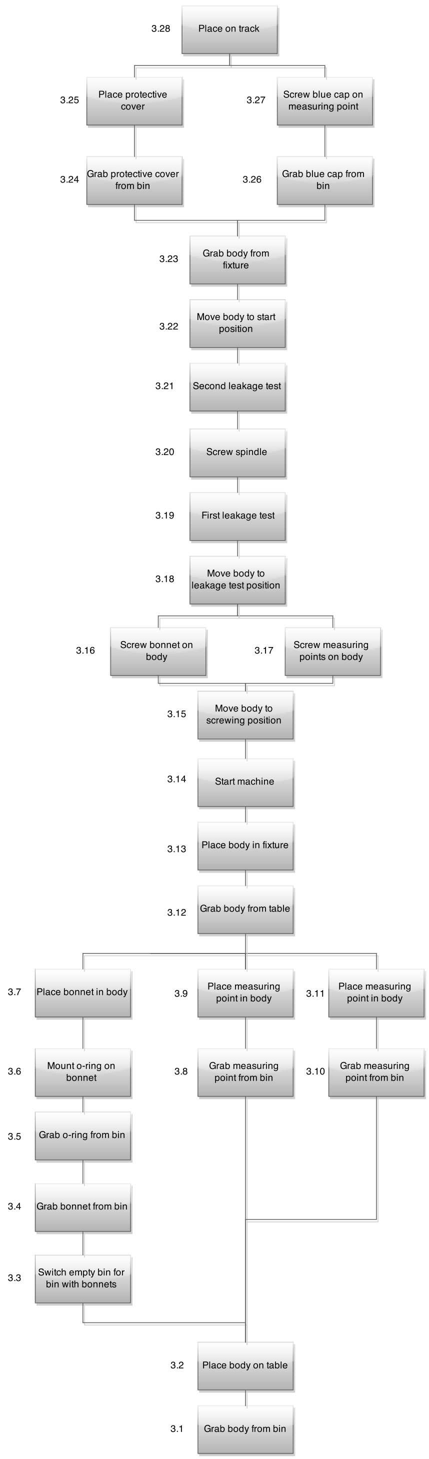
Appendix B - Hierarchical Task Analysis



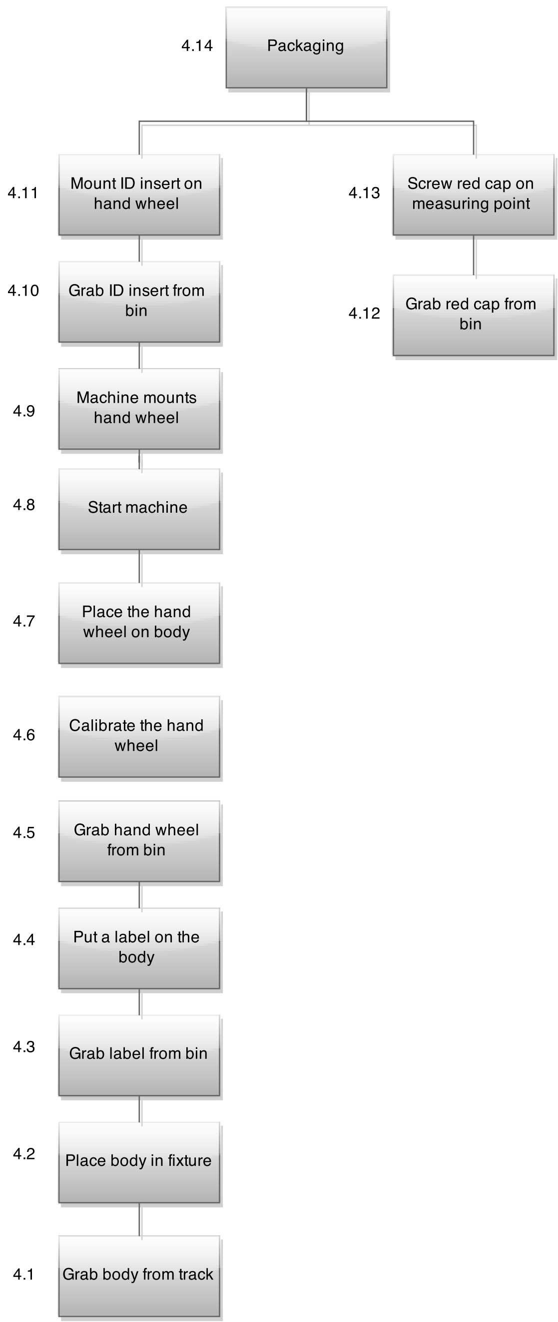
Station two - Assembly of Bonnet



Station three - Assembly of body



Station four - Final assembly and packaging



Appendix C - Table of LoA stations 1-4

LoA Table: Station 1

LoA Mech	Task number	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11
7												
6												
5									B	B		
4												
3												
2			B		B		B				B	
1		B		B		B		B				B

LoA info	Task number	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11
7												
6												
5									B	B		
4												
3			B		B		B	B				
2												
1		B		B		B					B	B

LoA Table: Station 2

LoA Mech	Task number	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18
7																			
6																			
5									B										
4																			
3																			
2			B		B	B				B		B		B		B		B	
1		B		B			B	B			B		B		B		B		B

LoA Mech	Task number	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28	2.29	2.30	2.31	2.32	2.33	2.34	2.35
7																		
6																		
5						B	B	B								B		
4																		
3																		
2		B		B					B			B		B			B	
1			B		B					B	B		B		B			B

LoA info	Task number	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18
7																			
6																			
5						B													
4																			
3			B	B	B				B	B		B		B		B		B	
2																			
1		B					B	B			B		B		B		B		B

LoA info	Task number	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28	2.29	2.30	2.31	2.32	2.33	2.34	2.35
7																		
6																		
5						B	B	B	B							B	B	
4																		
3		B		B	B						B	B		B	B			
2																		
1			B							B			B					B

LoA Table: Station 3

LoA Mech	Task number	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12	3.13	3.14	3.15	3.16	3.17	3.18	3.19	3.20	3.21	3.22	3.23	3.24	3.25	3.26	3.27	3.28
7																													
6																													
5																B	B	B	B	B	B	B	B						
4																													
3																													
2														B										B					
1		B	B	B	B	B	B	B	B	B	B	B	B		B										B	B	B	B	B

LoA info	Task number	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12	3.13	3.14	3.15	3.16	3.17	3.18	3.19	3.20	3.21	3.22	3.23	3.24	3.25	3.26	3.27	3.28
7																													
6																													
5																B	B	B	B	B	B	B	B						
4																													
3							B	B			B	B		B	B											B		B	
2																													
1		B	B	B	B	B			B	B			B											B	B		B		B

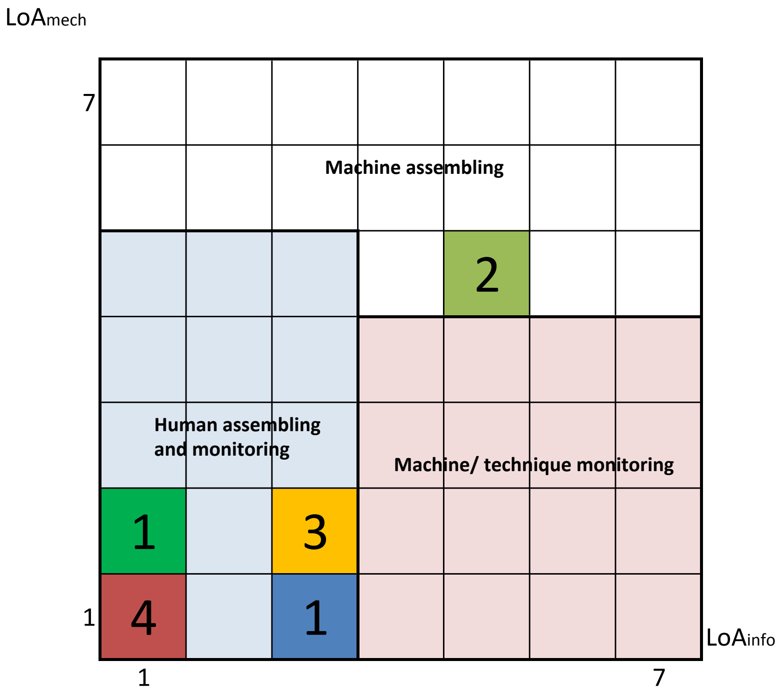
LoA Table: Station 4

LoA Mech	Task number	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.11	4.12	4.13	4.14
7															
6															
5										B					
4															
3															
2			B		B			B				B			B
1		B		B		B	B		B		B		B	B	

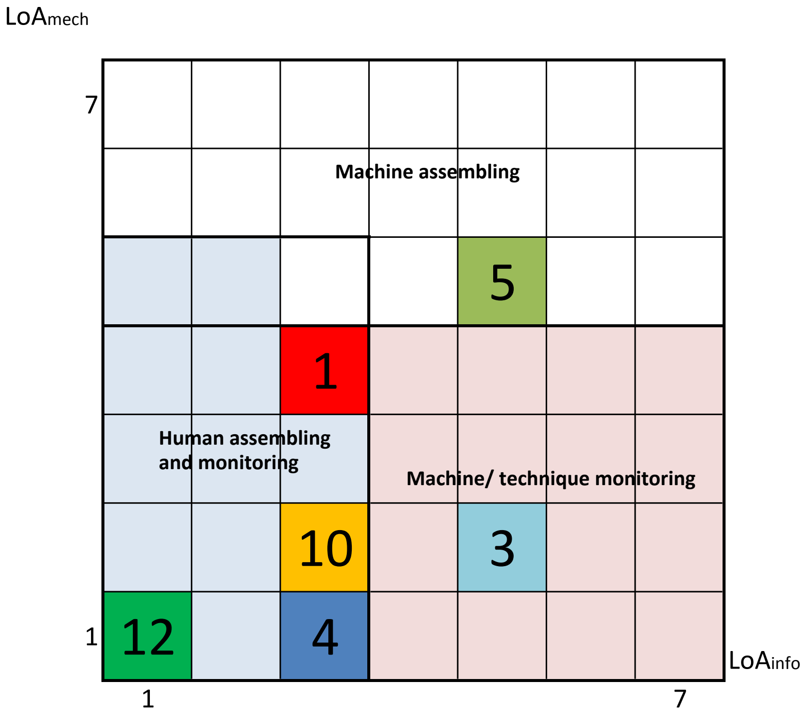
LoA info	Task number	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.11	4.12	4.13	4.14
7															
6															
5										B					
4															
3			B		B			B	B			B		B	B
2															
1		B		B		B	B				B		B		

Appendix D - LoA for stations 1-4

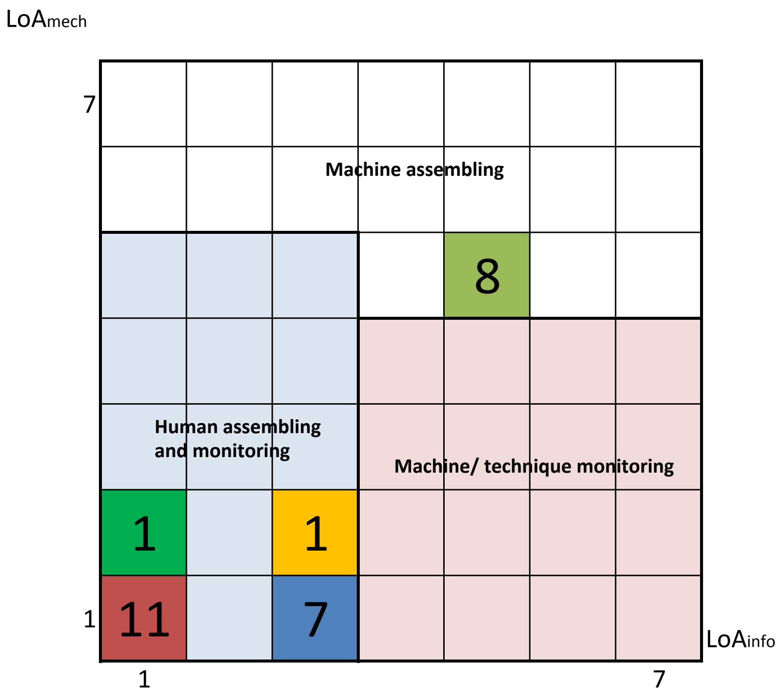
Station 1



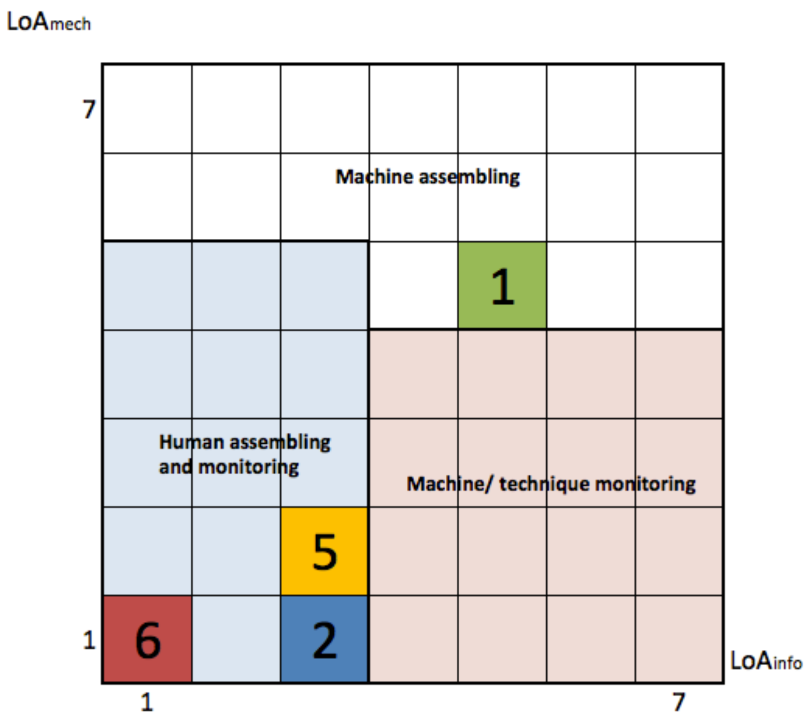
Station 2



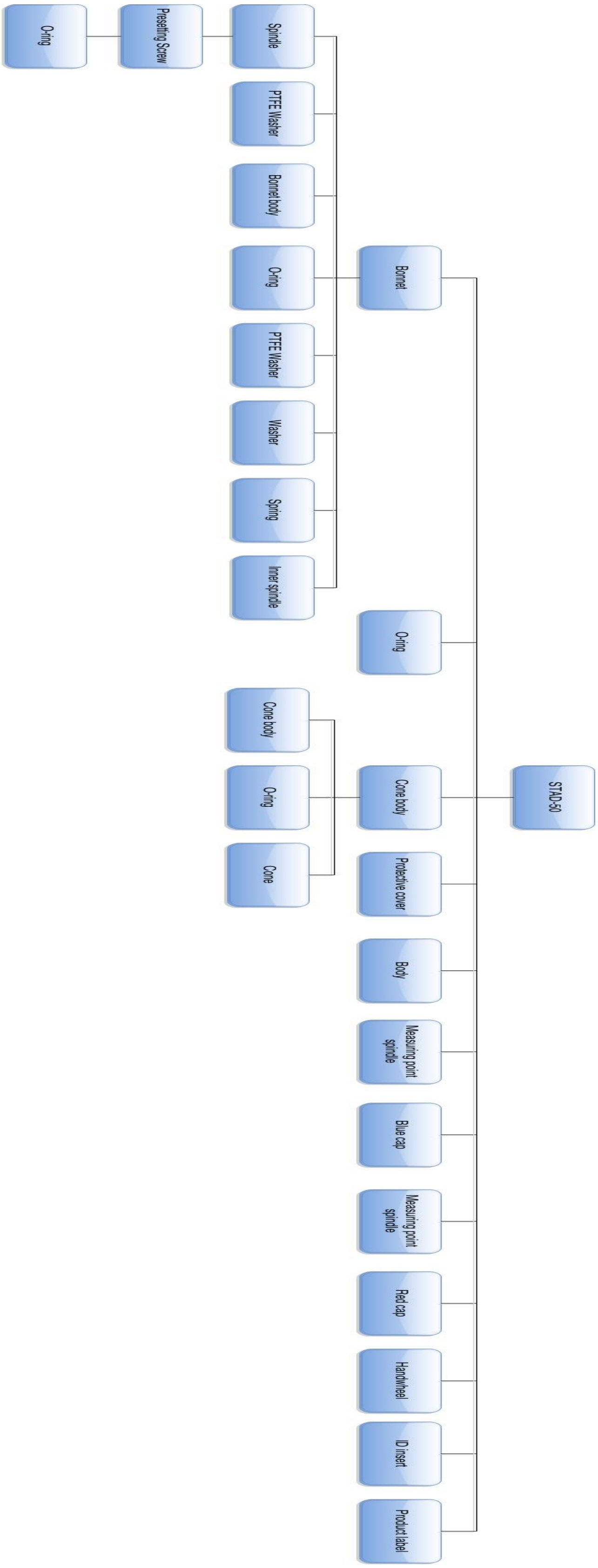
Station 3

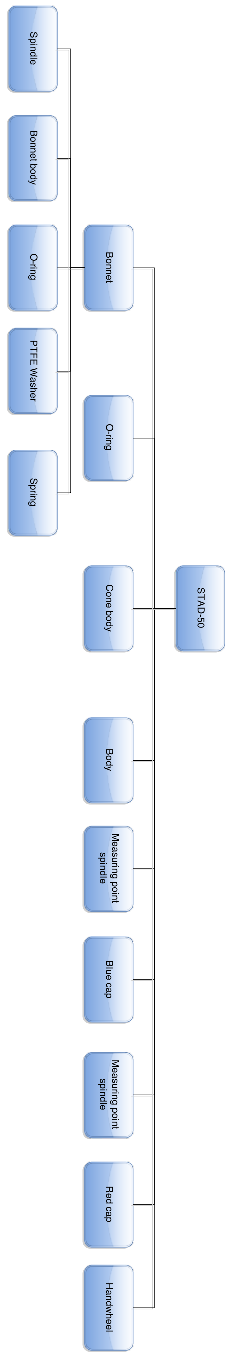


Station 4

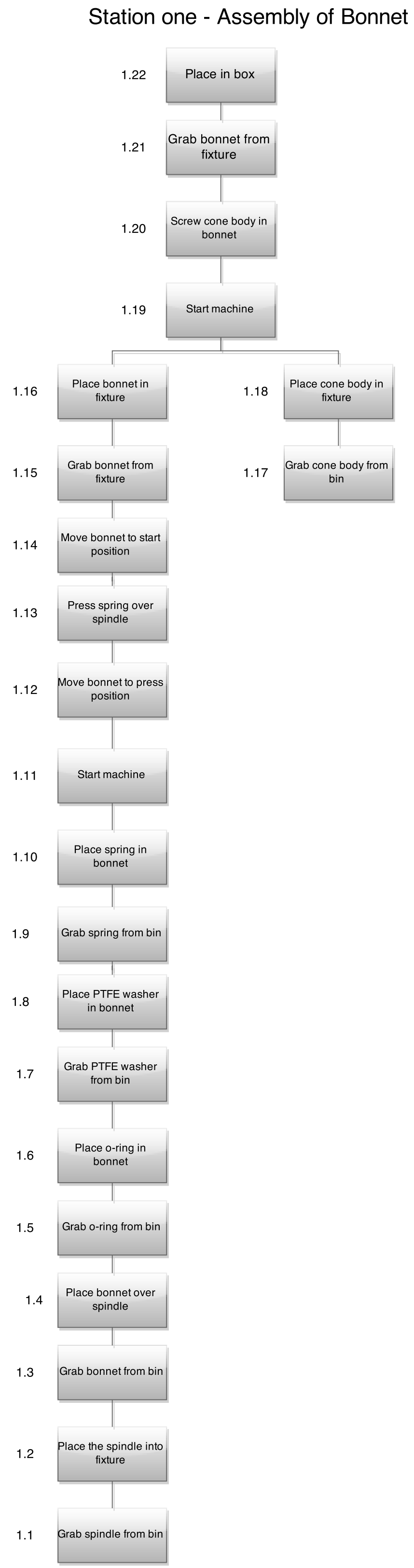


Appendix E - Bill of Material

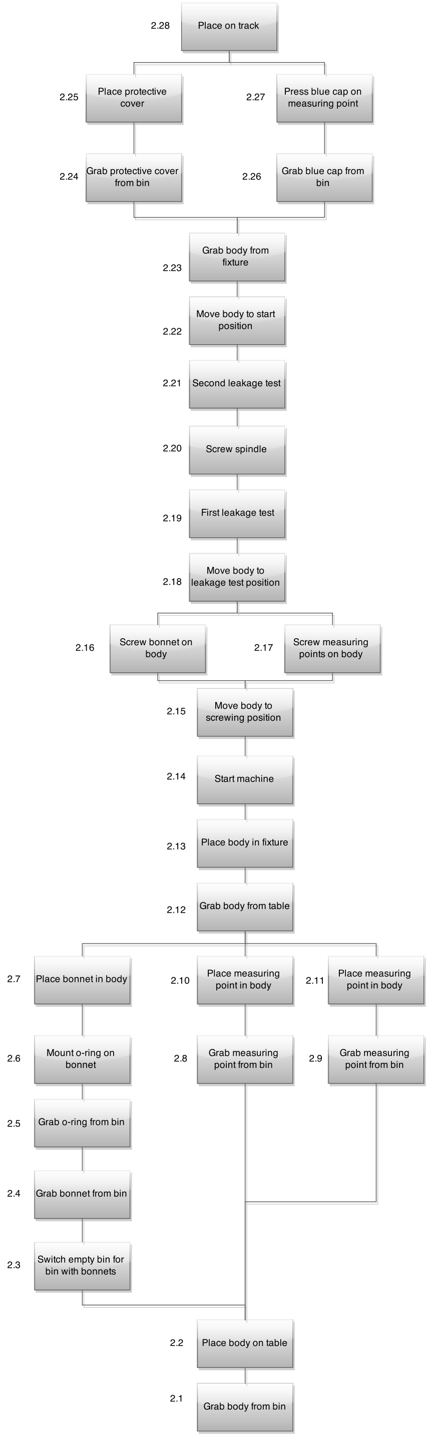



STAD-50
Bonnet
Spindle
Bonnet body
O-ring
PTFE Washer
Spring
O-ring
Cone body
Body
Measuring point spindle
Blue cap
Measuring point spindle
Red cap
Handwheel

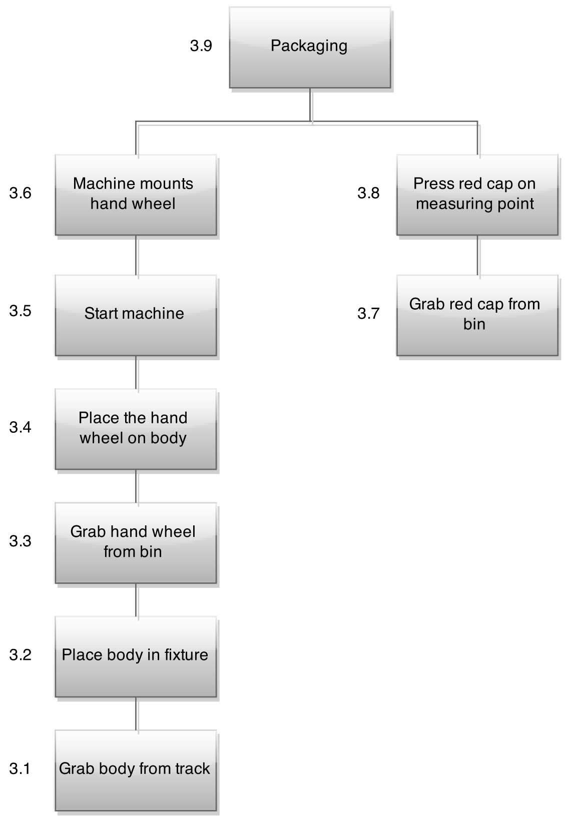
Appendix F - Hierarchical Task Analysis post DFA



Station two - Assembly of body



Station three - Final assembly and packaging



Appendix G - Interviews

Interview with Christofer Sundqvist, Manager Existing Products

Is any DFA-method used when designing a new product today and at what level?

How does the communication work between different departments when designing a new product? E.g. Production, foundry, quality etc.

At what time in a new project do you determine what equipment and machines to acquire?

How long is the process of changing material in a part of the product?

Is it possible to change the locking mechanism in the pre-setting screw?

How can you best integrate the ID-insert with the hand wheel?

Is it possible to integrate cone, cone body and O-ring into one single detail by using PEEK-plastic instead of AMETAL?

Is it possible to introduce a metal bellow in order to remove all the O-rings?

Is it possible to create chamfers on the spindle?

Interview with Leif Marstorp, Development Engineer

Thorough explanation of why the details exist in the way they do today.

Why is the angle of the spindle measure points as it is?

In what assembly order is the parts assembled in today's process?

Why isn't the cone and cone body integrated today?

Does the spindle measure points exist in different sizes or are they standard to fit every size of the STAD?

Is it possible to redesign the spindle to fit the O-ring on it instead of inside the bonnet?