Tools and machines for automatic assembly

A case study for finding automated assembly solutions

Bachelor of Science thesis in the Bachelor Degree Programme, Machine Engineering.

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ABSTRACT

This project took place at the R&D department at IMI Hydronic Engineering in Ljung and revolved around finding automated assembly solutions for one of the company's fluid balancing valve products; the STAD. IMI Hydronic Engineering is one of the world's leading companies in the manufacture of HVAC systems and is currently a branch under the IMI PLC Group.

The project was conducted through a case study on the STAD product family, but focused mainly on one dimension of the valve; The STAD 14/15 -50.

Automated assembly is an important factor to companies who wish to stay relevant and competitive in today's industry. This project discusses the abilities of automation for the STAD and different automation strategies for the product.

The Dynamo++ methodology accompanied by several methodical tools along with theoretical research into the relevant areas stood as a foundation for the results in the project.

The result is shown in two separate case approaches, one minimal investment case and one fully automated case. Each case is comprised of a concept solution along with explanations of invested equipment, mechanical- and cognitive improvements and the corresponding levels of automation.

The end results of these concepts are primarily measured by the overall decrease of the cycle time in the assembly process from the original setup. In the minimal investment case the cycle time decreased approximately by 25 %. In the fully automated case, a total decrease of more than 70 % was achieved.

The result yields insight to the use of Dynamo++, the concepts of different Levels of automation, how to increase or decrease these levels through concrete suggestions and how to adapt these methods and tools to other products and future projects.

ACKNOWLEDGMENT

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Darijan Jelica

Nomenclature

DYNAMO++	Methodology used for analysing the potential for automation in an existing system.
HTA	Hierarchical Task Analysis
BOM	Bill of Material
LoA	Levels of Automation
DFA	Design for Assembly
STAD DN 50	STAD Dimension 50 millimetres
SoPI	Square of Possible Improvements
SCARA robot	“Selective Compliance Assembly Robot Arm” robot
UR	Universal Robots
FIFO	First In First Out
HVAC	Heating, Ventilation and Air Conditioning
PTFE	Type of Teflon material

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INTRODUCTION

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.
To stay relevant it is crucial for companies to re-examine the process of assembly on a deeper lever and apply precise methods for calculations as well as powerful tools for improvement and innovation. Doing so with the vision of automatic assembly will not only lead to a higher profit margin, but a safer and more effective process in general. This chapter describes the intentions behind, and the path forward for that challenge.

1.1 Background

IMI, short for Imperial Metal Industries, is a company with its roots in England, dating as far back as 1862. Through the years the company has seen transformations from old areas of engineering to newer, more relevant fields accompanied by an expansion mainly across Europe, but with footprints across the entire globe. Today, the company is divided into three main branches: Critical-, Precision- and Hydronic engineering whom together employ over 12,000 people across the world.

IMI Hydronic Engineering produces an array of different kinds of products for HVAC systems. The vast majority of these products have been designed with manual assembly in mind. After product introduction there is sometimes a wish for automatic or semiautomatic assembly of the product to cut cost in production and get an even quality on the final products.

This change from manual to automatic assembly generally does not go smoothly, but tends to get very costly and the result is often a flawed process with the consequence of requiring a lot of work to make it function properly.

The tools and machines for the automated assembly solution usually has to be built to function with the design of the original details because changes in the details often generates a lot of extra work caused by the need for additional testing of the product functionality to meet the original specifications.

It is not rare for the result to show that just a part of the final assembly becomes automated due to the high complexity and cost associated with such a project.
With this in mind, one can make the argument that a semiautomatic solution would give lower savings than a fully automatic assembly process.

1.2 The project at IMI Hydronic Engineering

The project of finding automated solutions for the STAD-valve at IMI Hydronic Engineering was from the beginning able to grow or shrink in size, based on the number of people involved in it. According to the company's wishes for the projet the final number of participants was set to three. The approach for the project was set to result in two thesis reports, while simultaneously all three participants and the company agreed that the whole project should be worked from beginning to end by all three students. Simply speaking, this resulted in that the content of the first thesis would be the first half of the project, and the second half would be represented in the second thesis. This thesis covers the last phases of the project, and thus the first thesis should be read before this one to get a complete picture of the project.

To preserve the ability to read a single report, to understand it and to analyze the results, some parts of the project will naturally end up in both reports. This fact, along with regards to the rules associated with these kinds of reports means that the reader of either reports will find a limited difference in the first three chapters, other than what parts of the project the certain report covers. This will naturally be reflected in the later chapters by discussing the results of the project according to specific areas.

1.3 Project aim

The mission with the project is to examine an existing product of IMI Hydronic Engineering, the STAD 15/14 -50, and apply the DYNAMO++ method accompanied by several scientific tools to find solutions for an improved assembly process, and to investigate the possibilities for a fully automated assembly. The investigation regarding the fully automated solution will be based on previous studies in that field specifically.
Chosen methods will be thoroughly evaluated and adjusted to be suitable for the specific product in this study.

The result from the study on the STAD 15/14 -50 will be evaluated, and based on concrete examples the used method will be tweaked for optimization. The method used in this case study on the STAD will act as an example that can be applied on future projects or implemented on existing products.

IMI Hydronic Engineering also considers it a long lasting product with design features and component composition similar to many other, often more complex products.

Finally, the company's construction engineers will be educated in this chosen and adjusted method to be able to adapt future products for effective 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 family, the STAD valves, with the basis of evaluation being the STAD 15/14 -50. The STAD also comes in two different versions with every dimension, with or without a drain component. There are only a small number of sales connected to the drain version. The product was also designed for a customer to be able to buy the version without the drain, buy the drain component itself and then assemble it separately according to demand. Based on those facts the decision was made to only consider the version without the drain component in the manufacturing for this project. Furthermore the final stage of packaging the products will not be analyzed due to the time limitation of the project.

Because of the risk factor associated with major new purchases the project will not involve any actual investment in equipment by the company, but the end result will be limited to concrete suggestions and ideas.

1.5 Project questions

Specific core questions that will be answered in the report will be:

- Is it possible to automate the assembly process of the STAD?
- What kind of investment does this process need?
- Is it possible to increase the level of automation with a minimal investment approach?
- Is it possible to create a fully automated process for the whole STAD product family?
- How will the redesigned assembly process affect important assembly parameters?

METHOD

To achieve relevant measurements, a complete result along with a fulfilling discussion and a comprehensive conclusion the right method must be chosen. The content of this chapter is an explanation of the main method used for this project, Dynamo++ as well as a general presentation of the other moments in the project. Detailed explanations of the tools used in the Dynamo method along with explanations of the abbreviations and concepts in this chapter are located in the theory chapter.

2.1 Gathering of information

This step consists of several different methods of gathering the necessary information to get a clear and correct view of the current situation today at IMI Hydronic Engineering. One part of this process has also been based on more theoretical research into different areas of automation; this was aimed at getting inspiration and to generate creative ways of solving the problems of today and to envision the possible results desired for tomorrow.

2.1.1 Observations

According to Osvalder et al. (2010), observations are part of an objective method whose purpose is to gather the necessary information regarding the subject under study. Observations are intended to study the phenomena without affecting or intervening in it.

Observations can be divided into two main types, inside (active) observations and outside (passive) observations, according to Fasth (2012). The difference in these two types is that inside observations are done with the observer actively taking a part in the studied environment, e.g. the observer assemblies a product when studying an assembly process. Outside observations are when the observer studies the environment without actively affecting it, e.g. watching an operator assembly a product.

Furthermore the outside observations can be divided into two subtypes, direct and indirect observations. The difference between these two types is that direct observations require the observer to be present in the environment, while the indirect observations are rather done through a medium, e.g. films, pictures etc., according to Osvalder et al. (2010).

All of the observations done are of the outside type of observations. Because of the fact that the assembly of the STAD today is located in Poland, many of the necessary observations of the process have been done through documents sent from the engineers in that factory, i.e. indirect observations. The material consists of films on the assembly process at the different stations, excel spread sheets on essential information, containing cycle times, breakdowns and numbers on discarded products.

A lot of the necessary information was also derived from an analysis of the process done in the software Avix.

Some relevant observations have also been done at IMI Hydronic Engineering in Ljung through direct observation. Similar products, mainly the “STAF-valve” but also the “COMPACT-valve” are currently being assembled in the factory in Ljung and have some similar traits compared to the STAD.

For example the bonnet in STAD is identical in the STAF at certain dimensions. Furthermore the same machines are used for the assembly of the bonnet in Ljung and in Poland. Therefore it is justified to observe and analyse this part of the STAF assembly and use this information for conclusions regarding the STAD.

The assembly of the COMPACT in Ljung is currently a semi-automatic process, with the last station being fully automatic. Direct observations were made at this assembly area to examine solutions and concepts that may be transferable to the STAD.

Observations of the direct type were also done at a study visit at CEJN, a company manufacturing pneumatic valves located in Skövde, Sweden. The observations included both the production and manufacturing area of the company, but also a workshop held with the company’s engineers.

2.1.2 Literature study

To get a comprehensive understanding of the task and what paths to follow to solve it a broad literature study was carried out. The focus was to find scientific papers and theses in the relevant areas of the project. A great deal of interesting material was found through databases like Scopus, Web of Science, Google Scholar and in the catalogue of the Chalmers library.

After research on automated solutions within the company several offers by automation companies were found. One of these was on the STAD and dates back to February of 2001, right before the assembly was moved to Poland. The vision and performance of this automated system was studied to gain a concrete insight in a project with such a stunning similarity to the current one at IMI Hydronic Engineering.

2.2 When to automate

In an industrial survey conducted in 2006 regarding when to automate the top three answers were cost saving, to gain higher efficiency in the process and to increase competitiveness, according to Frohm (2008). The same survey shows that the top three answers on when not to automate were too many products or variants, investment cost or when the product is adapted for manufacturing. It becomes clear that automation is not a viable solution in every case for every product.

The assembly is the part of a products process where the most amount of human work takes place, according to Fasth (2012). It is therefore crucial to evaluate if the product in mind is suitable for automated assembly. Lotter et al. (2009) describes four important parameters that should be studied in detail when debating automation for a product:

- Productivity
- Flexibility
- Variant diversity
- Quantity

The relation of these parameters in terms of automation is shown in figure 1.

The figure also suggests different automation strategies according to these parameters.

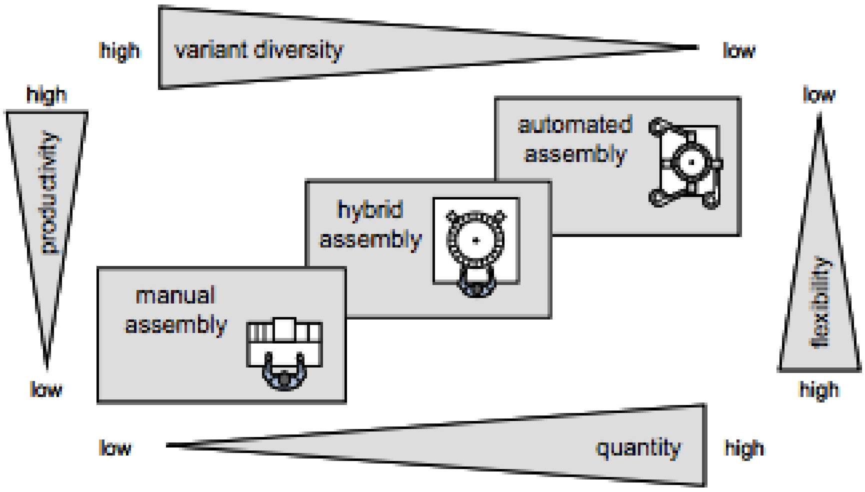


Figure 1. Automation strategies according to Lotter et al. (2009)

Heilala and Voho (2001) share the same view considering the parameters, but argue that the term “automated assembly” can be divided into “Flexible automation” and “Fixed special purpose automation”. Their take on automation strategy is shown in figure 2.

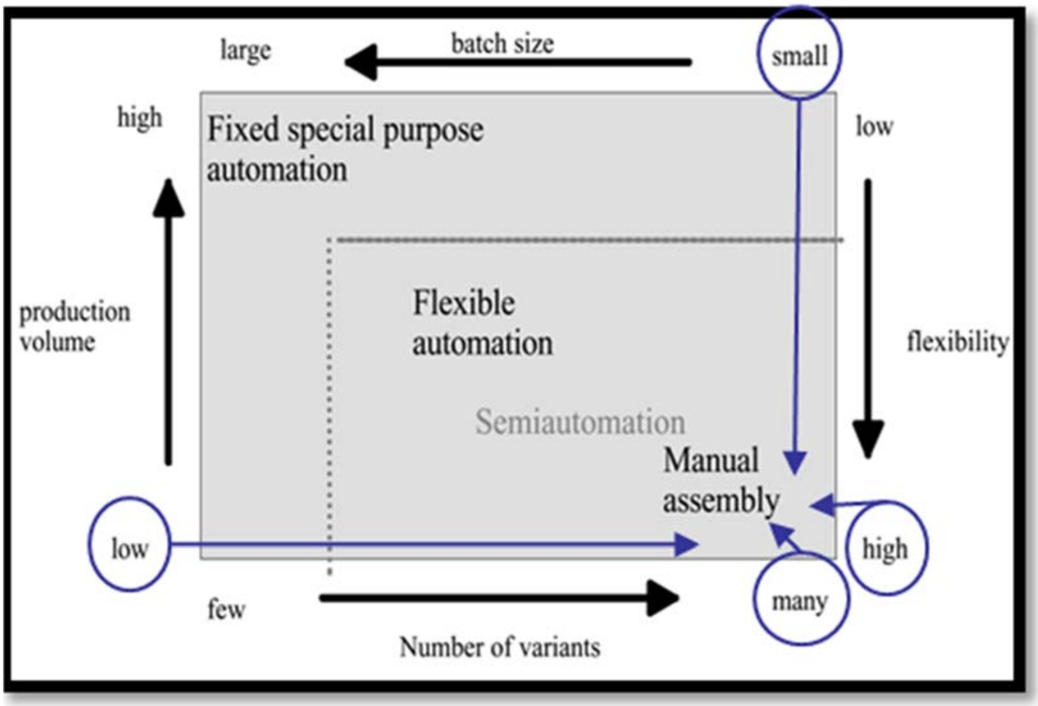


Figure 2. Automation strategies according to Heilala and Voho (2001).

From the figures a correlation between the parameters can be identified. Batch size and production volume are closely linked together as both are based on the number of products in the system. Furthermore they both dictate the same strategy, i.e. high/large productivity and batch size means the system should strive for high automation. On the other spectrum, flexibility and number of variants share a similar bond. They are both based on how much the system needs to be able to adapt and high/many flexibility and number of variants means the system should strive for a more manual, flexible assembly process.

2.3 The Dynamo Method

The DYNAMO++ methodology is used for measuring LoA (Levels of Automation) and in turn to find ways to change these levels according to situational needs and wishes. Fasth (2012) explains how the method saw its inception in 2004 with the development of the DYNAMO method, which was based in six case studies and subsequently validated by a seventh. This method was later refined and reworked between the years 2007-2009. This period saw four case studies for developing, and six studies for validating the new methodology: DYNAMO++, according to Fasth (2012).

The method is divided into four phases with three steps each. The first phase, 1) Pre study is consists of:

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

The second phase, 2) Measurement consists of:

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

The third phase, 3) Analysis consists of:

7. Conduct a workshop to decide the relevant Min- and Max levels of automation for the different tasks
8. Design the Square of possible improvements inside the LoA-matrix for the process
9. Analysis of the SoPI, task and operation optimization due to the time and flow parameters.

The fourth and final phase, 4) Implementation consists of:

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 have had on time and flow parameters

Following these phases and steps will result in understanding the current process and the problems associated with it. To increase or decrease LoA to avoid under- or over automated systems a set of tools can be used, for example DFA (Design For Assembly), HTA (Hierarchical Task Analysis), Line balancing etc. The method can be seen as an iterating tool to use multiple times for even better results illustrated in figure 3.

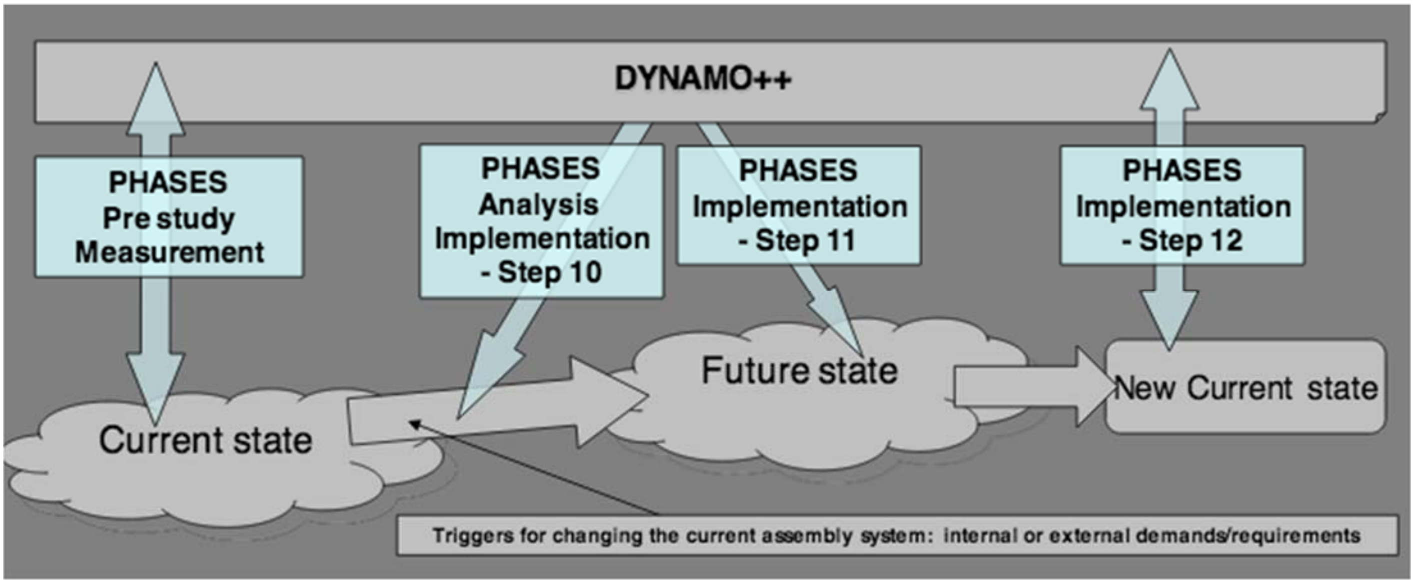


Figure 3. The phases of Dynamo++.

Another illustration of the method can be found in figure 4, this time displaying some of the tools often used in tandem with the method itself. This also showcases that some of the steps can be worked parallel with each other and is not necessarily to be bound to the original phase but should rather be used to the extent that the project requires.

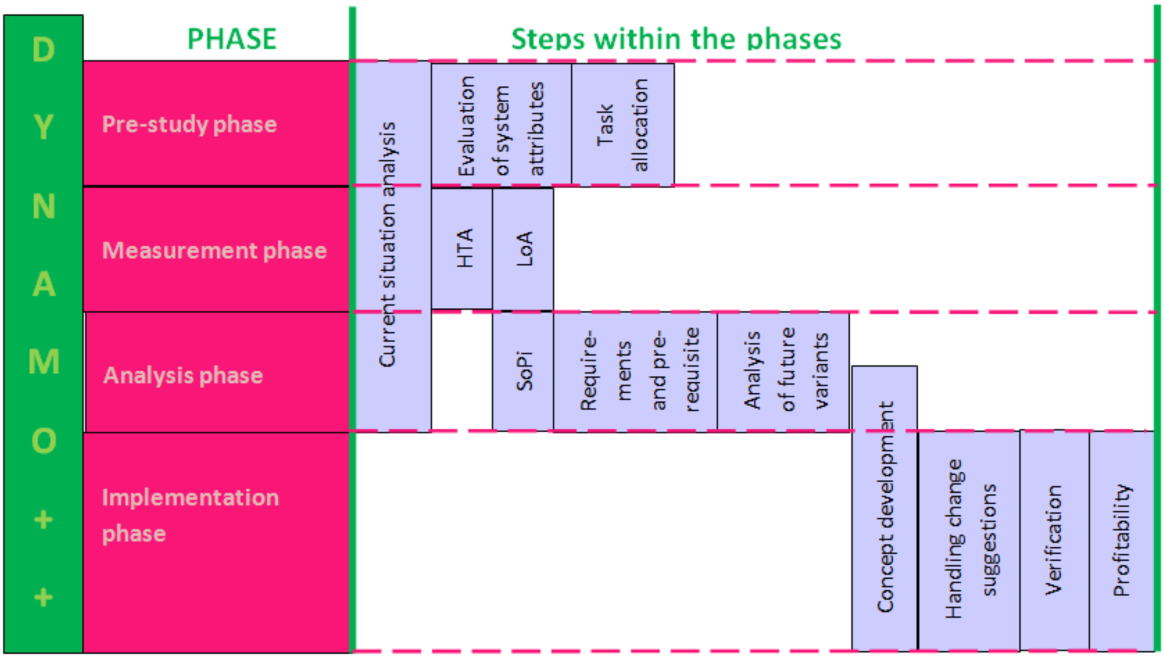


Figure 4. Another interpretation of the phases in the Dynamo++ method.

2.3.1 The use of Dynamo++

Due to the nature of the project, the steps of the Dynamo++ methodology were divided between the reports. The first thesis covers steps 1-7 along with the added step of a total DFA transformation of the product, while this thesis covers 7-10. Because of the delimitations of investment the two final steps of the method are naturally dismissed.

The seventh step, the workshop, is covered in both reports due to the fact that the event was carried out by all three students and yielded relevant results for both reports.

2.3.2 Workshop

A workshop was held at the company to highlight especially problematic areas of the assembly and to examine possible solutions for these problems. The event was also used to determine the possible increases in LoA for different tasks and subtasks. This was done to find high increases in desired parameters along with small investments to both time and cost. Furthermore, this was also done to avoid sub-optimizing and “leftover automation”.

More specifically, the workshop started out with a presentation about the current state of the STAD assembly. This step included complete pictures over LoA-matrixes and tables, and HTA’s of the STAD. An example of the LoA-matrixes and tables shown can be found in figures 5-6. The complete theory behind the LoA concept along with explanations of the tools used in Dynamo++ are shown in chapter 3. An example of the HTA shown can be found in appendix A.

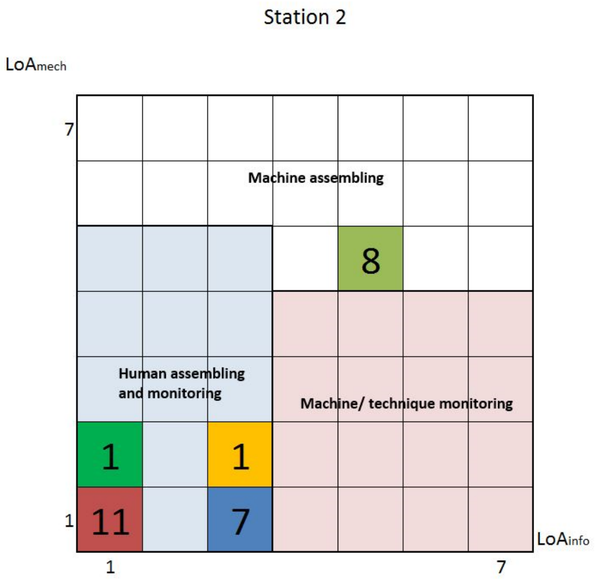
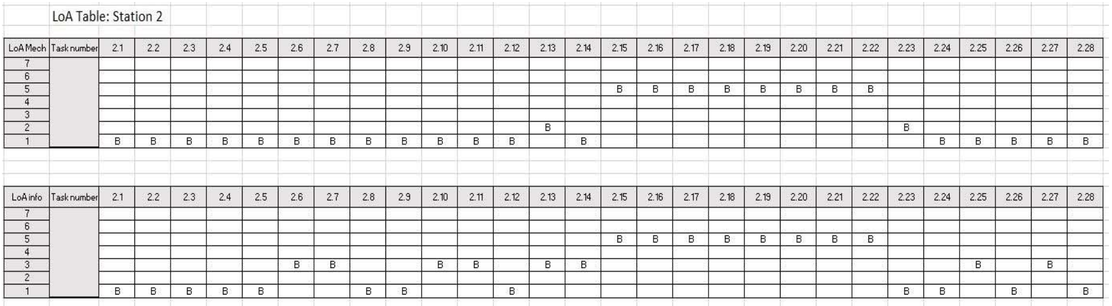


Figure 5. Example of how a LoA matrix can show where the tasks of a station are located in terms of mechanical & cognitive levels of automation. This figure shows these levels for the second station of the assembly.



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	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28
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	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	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27	2.28
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

Figure 6. Example of a LoA-table, which in detail shows what level of automation every task has.

Along with this, films of the assembly were shown to give the attendees even more insight to how the assembly is done today.

The next step of the workshop was basically brainstorming and overall generating of ideas and innovations connected to the assembly process, components, tasks and operations of the STAD. This was done in terms of predetermined areas chosen by the hosts of the workshop. In this case the areas were chosen to be the different stations of the current assembly layout, along with an area for a general discussion about LoA and one for DFA.

All the areas had information complementing the topic in mind, for example all areas covering the assembly stations had information on cycle times, number of tasks and components covered in that station, the corresponding HTA and LoA matrix and table. A set of pictures from the event can be found in appendix A.

Finally, every participant got three post-it notes with the numbers 1,2 and 3 on them. This was part of a ranking process of the generated ideas. The purpose of this was for the participants to place the note with the highest number next to the idea that they thought was the best one and so on. This step effectively delivered a compiled list of the “best” ideas, and a priority order could be documented.

2.4 The method for a fully automated solution

The aim of adopting the Dynamo++ methodology in this project was to find an improved state that was within reasonable timeframes, cost and difficulty to implement. The goal of the project from the beginning also included a vision of a fully automated solution that required additional research to be viewed as a feasible result.

To accomplish this, a plan was set in motion to study more theoretical literature on a higher academic scale along with state-of-the-art technology solutions within the robotics industry. The desired result of this was foremost to give an example of what equipment to obtain along with examples of other resources (tools etc.) in order to get a fully automatic, cutting-edge solution that would be the best possible.

The aspiration of this approach was to balance the results of the project to fit both goals achievable today and in the future. By using the Dynamo++ method, the engineers at IMI Hydronic Engineering can get an extensive knowledge of the assembly process today, get realistic goals to achieve in the near future, but also a vision for a near-perfect state in the art of assembly that can be worked towards for years to come. A visual representation of this approach can be found in figure 7.

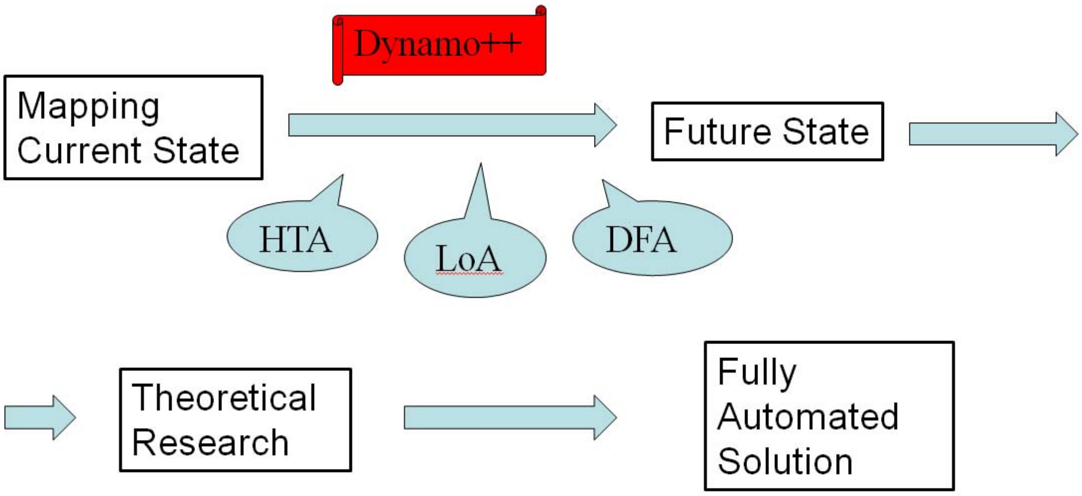


Figure 7. The approach of this project for achieving automatic assembly.

2.5 Validity and reliability

The term reliability is used to determine how well an external party beyond the original project can reiterate the project and achieve the same result. Validity is usually divided into two types, the first one being internal validity and the second one being external validity, according to Merriam (2006).

Internal validity measures how the achieved results in a project align with reality.

External validity qualifies how well the result can be generalized.

To ensure the validity of the achieved results in this project, the outcomes and conclusions have been discussed with befitting engineers, operators and managers. Furthermore the result was also matched to the existing theory of the subject at hand.

THEORY

This chapter documents and explains the necessary theories and thinking behind chosen tools and methods. Initially an explanation of the term automation is given, along with insight on how to identify and correctly categorize proper levels of automation. Furthermore this chapter gives insight to the terms HTA, LoA, SoPI and other tools included in the Dynamo++ method.

3.1 Automation

The term automation has a range of different meanings and where it should be applied differs between individuals. In order to use the word automation properly it is crucial to define the word, and how it relates to this project. Along with the definition of the term the advantages and disadvantages in accordance to products and processes will be discussed.

3.1.1 Definition of automation

Sheridan (2002) argues that automation more or less started in the 1940s, and gives an example of the world's first partly automated system containing a basic machine that replaced one single manually performed operation by using an electrical motor connected to a mechanism that would perform a single static task.

Sheridan (2002) further explains the concept of automation and argues that the definition has changed over time since the inception of the word. The definition: "Using automatic control to manufacture a product" is according to Sheridan (2002) vague and incomplete. He instead argues to define the term as: "Automation is the application of automatic control in all types of industries and scientific areas". This is the current and most accepted definition of automation in today's industry. As the technology of automation evolves, so does the definition of the term. With the development in recent years the definition is starting to change yet again. This time the scientific community is leaning towards relabeling automation as: "The use of electronics and mechanics to replace human interaction".

By human interaction Sheridan (2002) is referring to the physical work done by a human as well as the gathering of information, decision making and the communication between human and machine or machine to machine. A machine can solve these tasks with a range of instruments, such as different sensors, computers and mechanical actuators. A system like this can consist either with or without feedback and is illustrated in figure 8.

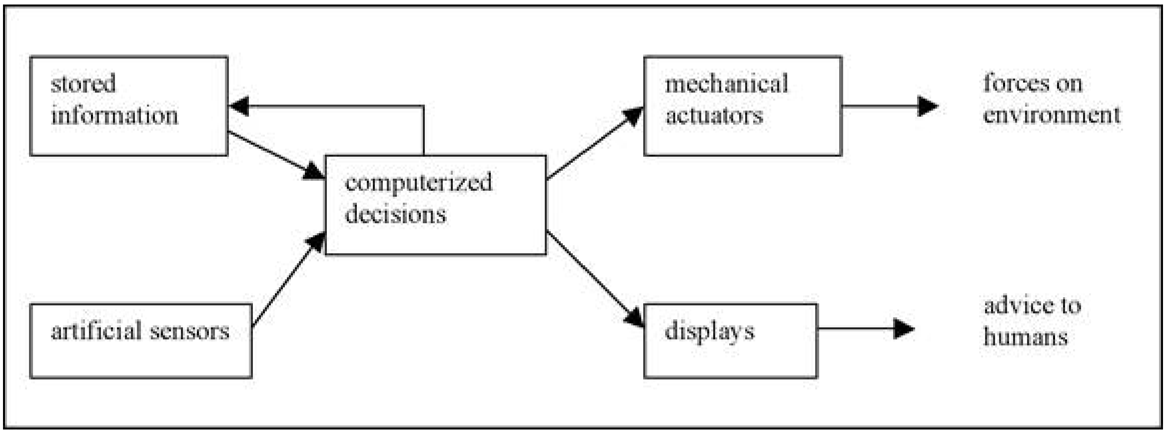


Figure 8. Visualization on how machines work with the environment around them, according to Sheridan (2002).

3.1.2 Levels of automation

The simplest way to observe automation is in the separate states of either manual or automatic, according to Frohm (2008). This perspective gives the impression that manual labor evolves into a fully automatic system in a single step although the process in reality is much more complicated. Stemming from that situation, a need to observe automation in a more comprehensive and detailed way arises. Rather than having two clearly separated states, a more accurate definition of the automation level in a system is required, as well as the relation between the different levels.

There are several different definitions of the concept Level of Automation by a range of authors and engineers and it is often described as the interference between humans and machines. Kern and Schumann (1985) describe it as: “Degree of mechanization is defined as the technical level in five different dimensions or work functions”. Others have a slightly different approach to the concept. Thomas Sheridan (1980), a professor at MIT, describes Levels of Automation as: “The level of automation incorporates the issue of feedback as well as relative sharing of functions in ten stages”. By the definitions alone, the statements of Kern et al. (1985) and Sheridan (1980) differ from one another, but that does not mean that they would explicitly disagree with each other or that one of them is mistaken. The authors are simply defining different type of automations. Kern and Schumann (1985) are addressing the mechanical level of automation; meaning at what level the machine is executing the task by its own. Sheridan (1980) discusses the levels of computerization, meaning the interaction of a joint human-computer decision making during the task.

Frohm (2008) in turn 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”. The cognitive tasks Frohm is talking about is specifically the automation of information mentioned by Fasth et al. (2009). As for the physical tasks, Frohm is referring to the level of automation of mechanical activities. Hence, Frohm recognizes both the importance of Sheridan’s cognitive- and Kern and Schumann’s mechanical definition. His definition subsequently gives the most accurate picture in terms of what is important to consider in such processes today. He argues that the levels of cognitive and mechanical automation are necessary to review, but needs to be done so separately. The two types of automation will then together decide the complete level of automation of the task presented in an evaluation matrix, shown in figure 9.

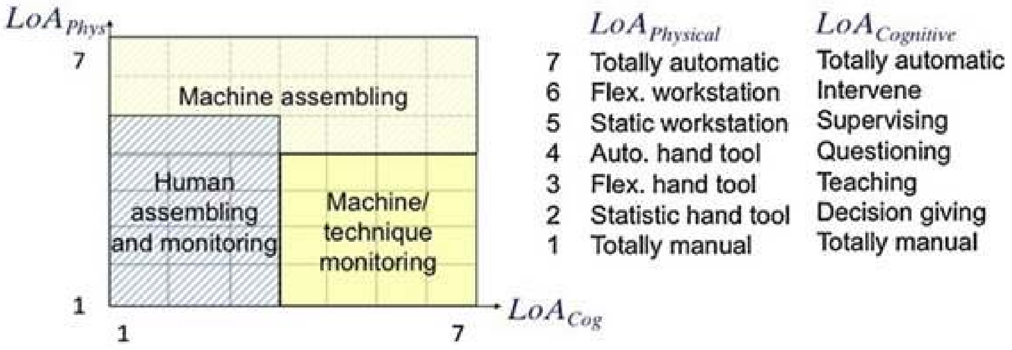
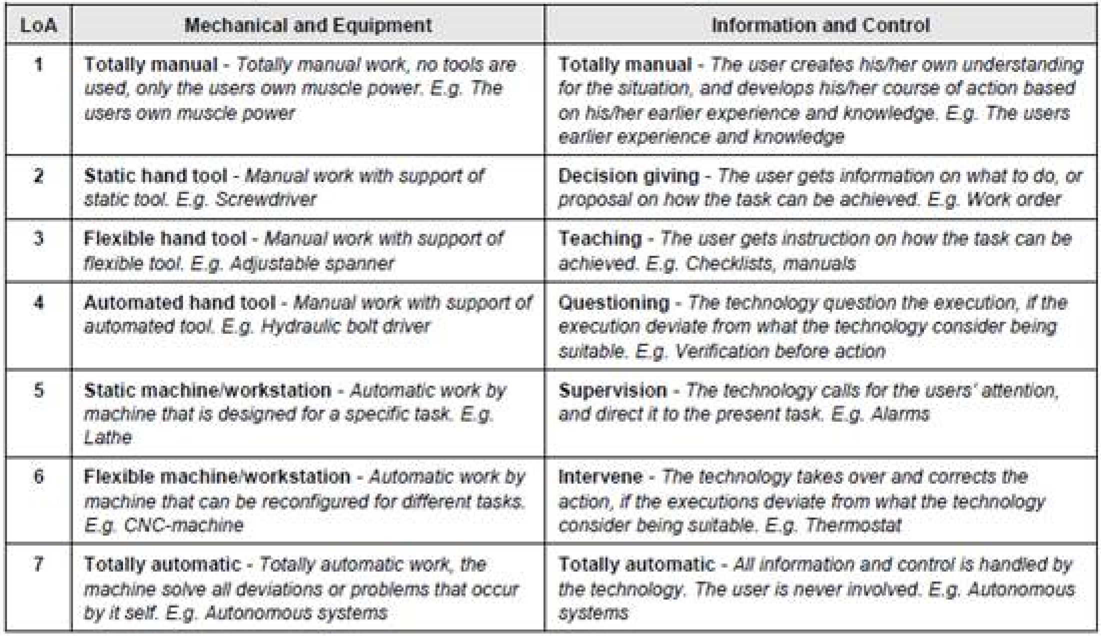


Figure 9. LoA matrix with level examples, according to Fasth et al. (2009)

This matrix shows where the task is located in regards to automation level from both mechanical and cognitive perspectives. To quantify these levels, a definition of every level for both mechanical and cognitive LoA is shown in figure 10. Furthermore, the measurement and mapping of LoA through observations and tools like this matrix can then act as a foundation to estimate the potential increase or decrease of automation and technology in a manufacturing system, according to Frohm (2008).



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 10. A more detailed description on how to determine the correct level of automation, according to Frohm (2008).

3.2 Hierarchical task analysis

In order to analyse and understand every step of an important task the engineering tool hierarchical task analysis can be utilized (shown in figure 11). The tool takes a task and subsequently breaks it down into subtasks and operations to give the observer an overlook of the process and in what order operations need to be carried out to complete the task in question. The simplest and best way to construct an accurate HTA is to observe the process in action to map out all the tasks performed by the operators. To get a more comprehensive understanding of how the tasks are being done individual interviews with the personnel can also be held. If present, already existing work manuals and checklists can also be used to collect the necessary data.

The initial step of the tool is to identify and choose the main goal of the process. In the case of this project that goal would amount to a fully assembled STAD. That goal is then divided into subtasks that are necessary to complete before achieving the main goal. The next step is to further divide the subtasks into operations that need to be completed for the sake of completing a subtask. This step can be done multiple times to satisfy the wanted outcome of the tool. The number of iterations is often bound by the level of complexity of the product or process under scrutiny. The nature of the ”operations” that are placed at the bottom in the HTA can be of two kinds and thus contain two types of information according to Osvalder et al. (2010). They can be describing the operation itself, for example”press green button”, and secondly they can also describe the desired outcome of the operation, for example”start pressing machine”.

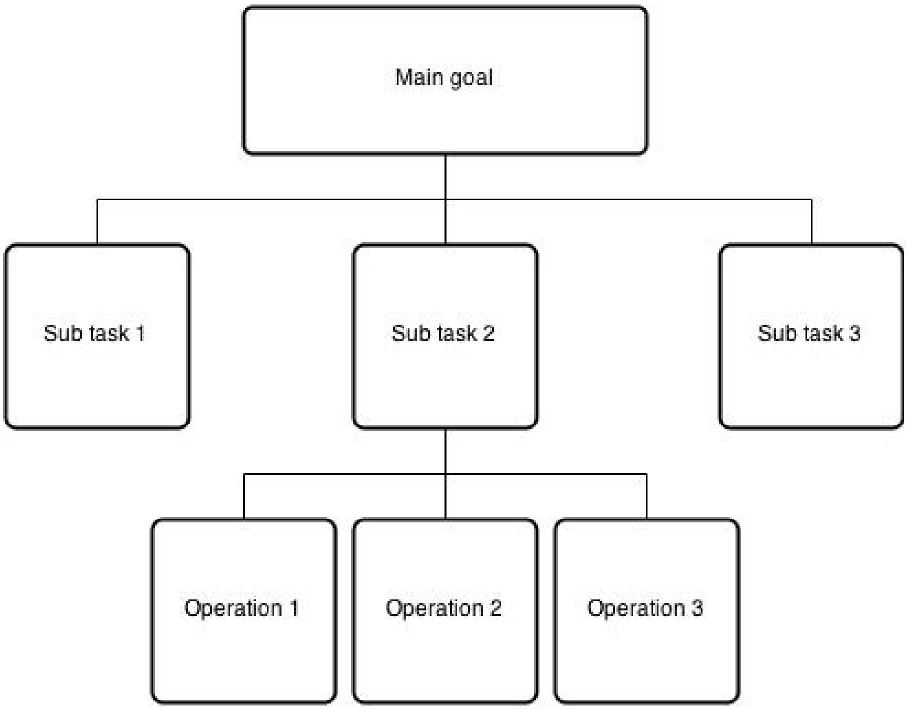


Figure 11. Showing the general idea of a HTA.

3.3 Tools and machines

This chapter defines the tools and machines used in later chapters to give an overview of functions, flexibility etc. for different equipment.

3.3.1 Flexible machines

The definition of an industrial robot is: “An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications” (ISO 8373). The machines that satisfy this standard can be used in specific situations to achieve unique results, and should be used in regard to this. An industrial robot can also vary in its satisfaction of the parameters found in the definition, e.g. control, axes, multipurpose etc. Different robots can have a different number of axes, degrees of freedom, how to program it or overall flexibility.

Flexibility is defined by Bolmsjö (2006) as ”a systems ability to adapt to changes in the process”. He further defines four key areas to where to evaluate flexibility:

- Product flexibility
- Capacity flexibility
- Equipment flexibility
- Manufacture flexibility

To define if a machine is flexible it needs to be evaluated according to changes in these areas. The measurement of this can be based in several parameters that are important to a specific situation or system. Examples of such parameters are:

- Changing the number of components in a product
- Changing the size of the product
- Change in manufacturing volume
- Change in necessary tools
- Changes in regard to redesign

3.3.2 Vibratory-bowl feeders

A vibratory bowl feeder is a machine used to feed and orient parts in a desired fashion. A system consisting of one of these machines is usually connected to a feed track device along with sensors to determine when the feeder should be in drift or rest. The track is usually connected to some kind of machine that moves the oriented parts into whatever system it should be fitted, for example flexible or static robots. Boothroyd (2005) determines that “The vibratory-bowl feeder is the most versatile of all hopper feeding devices for small engineering parts”. Such a feeder is shown in figure 12. Through observations the versatility of these feeders and its widespread use throughout the industry could be confirmed.

Figure 12. A typical vibratory-bowl feeder.

3.3.3 Vision systems

Vision systems are more often than not part of modern automated assembly solutions. This is because of the benefit in orientation they provide when integrated with other parts of the assembly process, most notably flexible industrial robots. Danauskis (2014) describes a vision system as consisting of a camera (often mounted vertically from what its supposed to photograph), and a computer analysing the images. Bolmsjö (2006) describes it in further detail, explaining the different tools in the system, for example pixel counter, angle measurer, defect seeker etc. Danauskis (2014) further describes in a broader sense, saying it can be used as the “eyes for inspection and positioning”. From this definition a number of areas of application can be identified. Some key areas for use are:

- Counting
- Measuring
- Detecting
- Recognizing
- Finding

Furthermore Danauskis (2014) argues that vision systems can play an important role in automation solutions due to the fact that such systems are often calibrated to be highly precise along with high repeatability. A typical vision system is shown in figure 13.

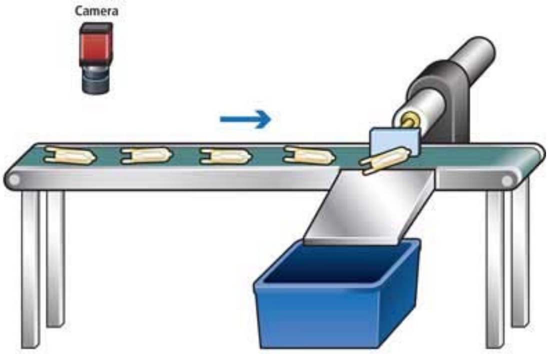


Figure 13. The concept behind a typical vision system.

EMPIRICS

Using the described methods and tools specific results were documented. This chapter discloses those results based on the theory and what occurred with the case study at the company. This chapter in turn is the basis for the elements of the discussion and the content of the analysis of the project questions.

4.1 The new product

In the first half of the project a thorough redesign of the product was made for it to better suit automated assembly. This “new product” is the basis for the assembly solutions in the following chapter. To get a total understanding for how the product works and the function for every part, chapter four of the first report is recommended. For the sake of continuity the same assembly process as the current one in Poland is used for the new product. The “theoretical current state” for the STAD is presented below in regard to number of components, current tasks and the corresponding level of automations. The cycle time for the new product is currently the same as the cycle time at the assembly in Poland: 37,7 seconds.

4.1.1 Bill of materials

A BOM was compiled over the remaining components of the redesigned product and can be found in appendix B. To recap the structure of the product a short summary follows. Only one subassembly, the bonnet, is required. The bonnet consists of a spindle, bonnet body, O-ring, PTFE washer and a spring. The next step of the process assembles the final product. This assembly consists of a body, O-ring, two measure points and two corresponding capholders (one red and one blue), protective cover, hand-wheel, cone body and the sub-assembled bonnet.

4.1.2 Hierarchical task analysis

The HTA precisely represents the required tasks and actions for the current assembly process along with the LoA for every task. This part is presented in several figures, found in appendix C.

The DFA made significant changes to the number of components in the product, but did not offer any solution on how to complete the operations in the assembly process. Therefore, the HTA currently connected to the product is not complete, but rather based on the existing assembly process with the reduction of components in mind. A new HTA was done in every specific case solution to match the corresponding assembly process.

In this HTA, the first station has a total of 35 operations. The second station contains 28 operations. The third and final station has 14 operations. This results in that the assembly process for the STAD requires a total of 59 operations.

4.2 Should automation be implemented?

Based on the parameters discussed in chapter 2.2 an evaluation of the STAD was completed.

The annual sales of the STAD product family are usually close over a million units. This number is based on information obtained from the sales division at IMI Hydronic Engineering. Such a high number means this product ends up in the high part of the spectrum of both the quantity and production parameters.

It was also evaluated that the STAD ends up in the lower parts of the spectrum concerning flexibility and product variation. This is due to the fact that a reasonably high number of parts are identical between the different sizes of the STAD product family, more exactly: one O-ring, two measuring points, two capholders, hand-wheel, protective cover, two PTFE-washers, pre-setting screw and ID insert. Two other products at IMI Hydronic Engineering are also very similar to the STAD. The STAF-valve incorporates the same bonnet as the STAD. The only difference between the STAD and the STAV-valve is that the STAV is composed of a different body. This means that a highly automated assembly process for the STAD will be useful in many applications and situations despite being fairly inflexible.

Based on these conclusions it was decided that the STAD should strive towards the higher end of the automation spectrum showed by the figures in chapter 2.2. In respect of the company’s wishes for flexible equipment along with the fact that some parts differ in size and design between dimensions of the STAD and in the cases of the similar products the final automation aim was set to “flexible automation”.

4.3 Levels of automation

The levels of automation are presented in three matrixes, one per current assembly station.

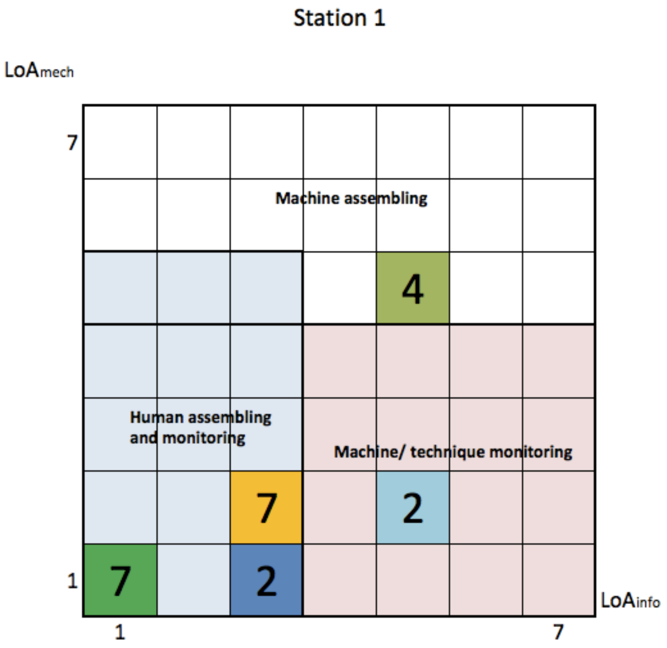


Figure 14, Showing the LoA for the first station. The number in each box correlates to the amount of tasks that hold that Level of automation.

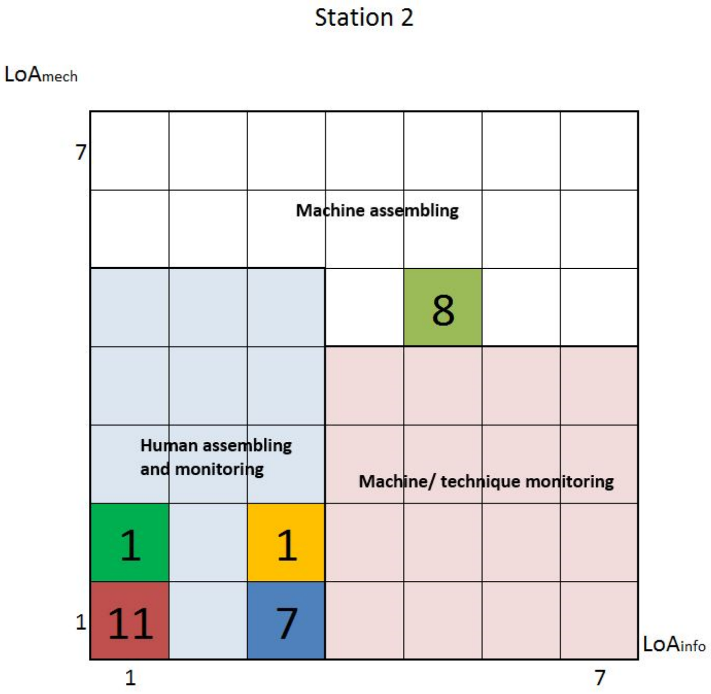


Figure 15, the LoA for the second station.

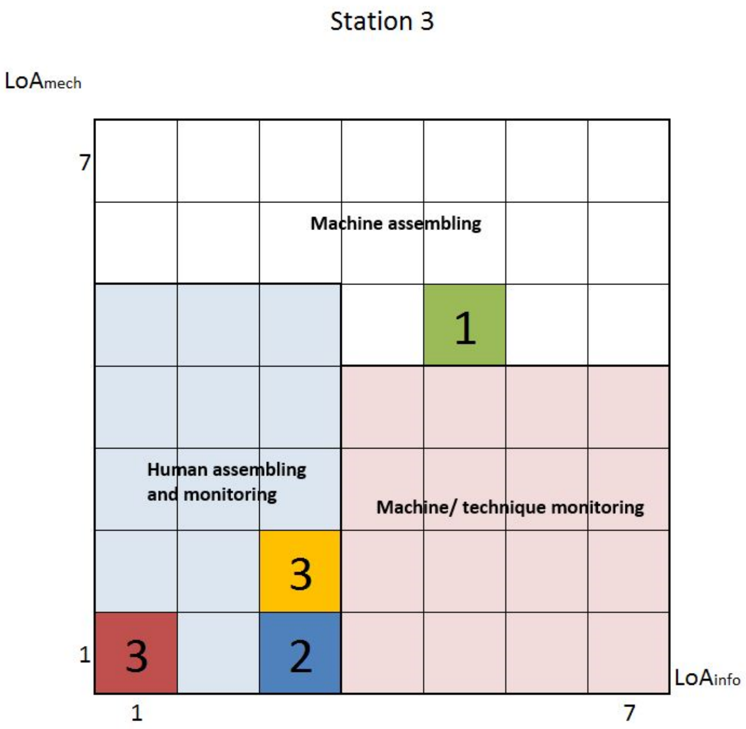


Figure 16, the LoA for the third and final station.

4.4 Workshop

The workshop resulted in several innovative ideas concerning the assembly of the STAD. Roughly speaking half of the generated ideas revolved around DFA and the product directly. These ideas are included in the first report. The rest were more closely linked to the process and are shown in this report.

The following list contains the ideas from the workshop in the order of the most points obtained by the attendees. The number in the parenthesis shows the points the idea gathered.

1. Invest in cheap and most importantly flexible robots (8)
2. Design a new testing method of the valves with helium as the testing-medium instead of air (7)
3. Develop the assembly solution parallel with the development of a new product. Specify the desired LoA-level in the specification of requirements for the product. (5)
4. Invest in television-screens at the assembly stations showing instructions of the assembly process. (3)
5. Use a feeder for O-rings. (0)
6. Invest in treadmills and rotary tables for the transportation of the product between stations. (0)

7. Implement an alarm-system designed to alert the operator if the parts assembled are done so in the wrong order. (0)
8. Change the current mechanism for pressing the hand wheel on to the assembled product. (0)

The first idea generated the most points out of all the ideas from the workshop with eight points. The idea itself is very general, but it shows that the company wishes for an automated solution above all else.

The second idea is referring to the bottleneck operation today. The leakage test of the valves is by far the operation that takes the most time. Solutions for this problem based in changing the fluid of the test to helium can be found in today’s industry. Such an implementation would drastically change the premise of the layout and the capabilities of line balancing.

The third suggestion refers to the development cycle of a product at IMI Hydronic Engineering. At the workshop a discussion was held on this area and it was concluded that in the current development cycle of a new product the development team have very little communication with the people responsible for the assembly. This dialogue is almost exclusively held in the end part of the project where the production engineers get specifications on product components and functions and have to adapt accordingly. This suggestion aims to improve that conversation and to implement LoA-requirements in an earlier stage of the project.

According to figure 10, the definition of a cognitive LoA of three is: “The user gets instruction on how the task can be achieved. E.g. Checklists, manuals.” A system equipped with television screens showing the correct way of doing a certain set of tasks would accomplish this requirement quite gracefully. Furthermore, the screens have the capability of keeping the correct takt time of the station. Every station has a certain time in which it is necessary to produce a product that is adapted to meet both economic and ergonomic requirements. With this time in mind, the screens can show the assembly done in exactly that time playing in a loop. That way the operator can follow *how* to do the task, but also *how fast* to do it. By implementing this system, the whole process will be better balanced, leading to higher repeatability time-wise. This in turn leads to a better a better basis for improvements.

The fifth suggestion again is a very general one. Stemming from the problems associated with grabbing and placing O-rings in an assembly process the solution of investing in vibratory bowl feeders came to mind.

The sixth idea tackles the problem of transporting parts between stations. If this is done by treadmill or rotary tables the LoA can increase and the time spent on “waste operations” such as transport will be minimized.

Suggestion number seven aims to increase the cognitive LoA for operations mainly at the first station. By implementing an alarm system designed to keep track of the operations involved in picking and placing parts these tasks could be raised to the fifth level of cognitive LoA. This could be done for example by a vision system aimed at the fixture for the spindle programmed to alert the operator if the geometries of the parts come in the wrong order.

The eight idea discusses possibilities of changing how the hand wheel is pressed on to the bonnet today. Currently the hand wheel is placed in the correct position by the operator and then pressed into place by a machine. This pressing machine requires two products to perform its task. The idea was to find a way to change this to enable the option of only pressing one product at a time. This was mainly to increase the flexibility of the process as the third operator waits quite a while for partly assembled products from station two.

4.5 The square of possible improvements

By examining the LoA-matrixes for the different stations a clear pattern can be identified. The majority of the operations are located in the lower 3x3-box of the matrix. Most of these operations are similar to each other in execution as well, for example pushing buttons along with grabbing and placing parts. To simplify the separation these operations will be referred to as “pick and place”-operations.

There are a few exceptions to this group of tasks. A total of 13 of the operations are all located in the (5,5) position of the matrix. These are the operations that require a mechanical force of some kind that an operator cannot satisfy with his or her own hands. Some examples of this are the pressing of the spring over the spindle and the leakage test. Therefore, these operations need to be done by machines of some sort and today all of these operations occupy the same level of automation. With this in mind, the chosen approach for the SoPI-analysis was to look at these mechanical operations separately and as a lone operation for the creation of the SoPI. Secondly all the pick and place operations from all three stations were also grouped into a total of five separate operations and to create a SoPI for these as well. LoA matrixes for both perspectives of the process are shown in figures 17 and 19 respectively.

The decision of where to construct the SoPI-box was dependent on available equipment in the automation industry today, ideas generated from the workshop and on observations of the current assembly process together with external automation solutions on similar products found through research.

4.5.1 The mechanical part of the assembly process

For the mechanical part of the process (operations shown in terms of LoA in figure 17) the SoPI was set to a 2x2 box located between (5,5) and (6,6) as shown in figure 18. The reason it doesn’t reach down to the lower levels is that the act of lowering the LoA for certain operations usually brings investment cost and thus the most simple and minimal solution for the process is to leave these operations in the LoA that they are.

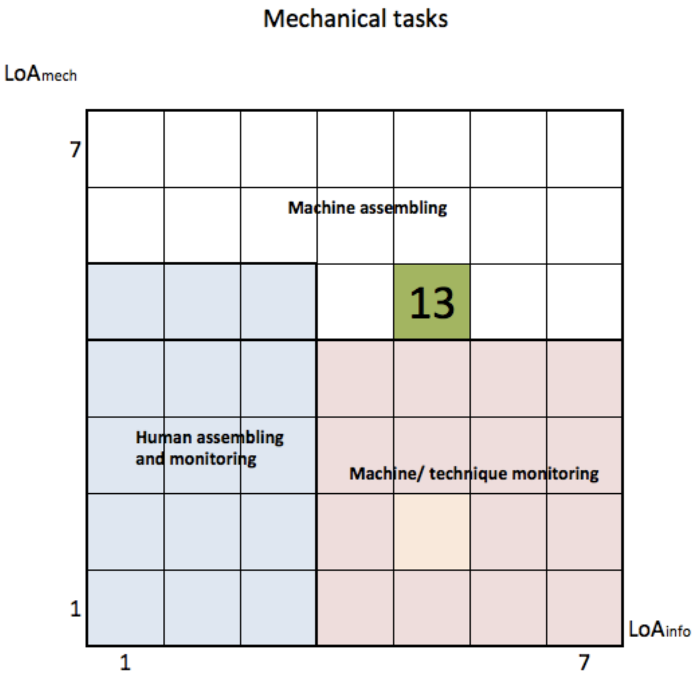


Figure 17. LoA matrix for mechanical operations for the whole process.

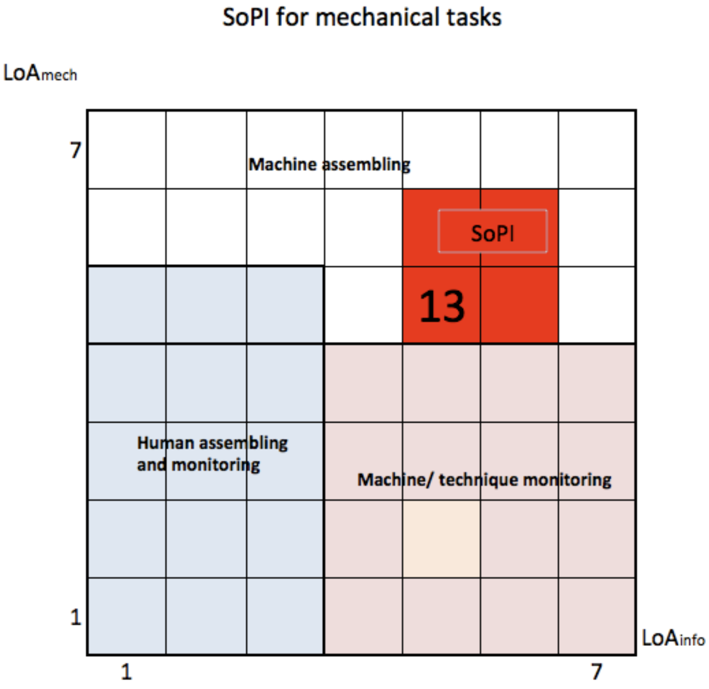


Figure 18. SoPI for the mechanical tasks.

4.5.2 The pick and place operations of the assembly process

Because of the nature of the pick and place operations and the potential for improvements a much bigger SoPI was constructed in this phase. The SoPI for each group of operations was almost unanimous in how it looks. The only exception is the eleven operations located in the (1,3) square in figure 19. These operations were considered to be able to stay at a mechanical level of one to be compatible with the present task. However, considering the whole assembly these operations had to be brought up to a minimum level of two for the mechanical LoA in order to be compatible with the process. The final SoPI for the pick and place operations is shown in figure 20.

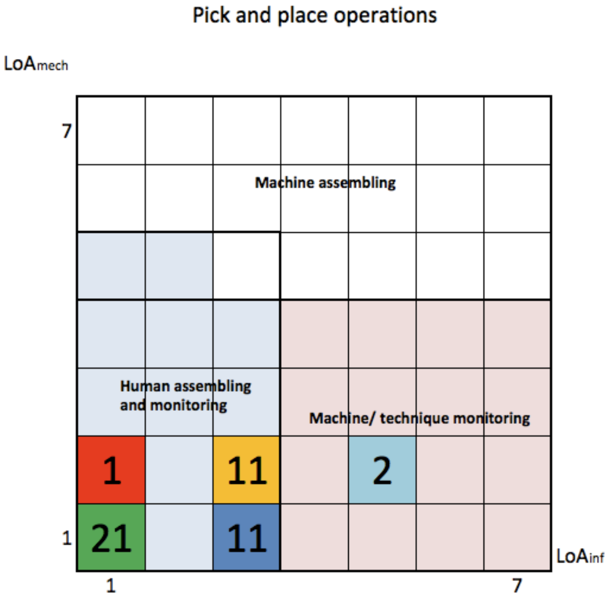


Figure 19. LoA-matrix for pick and place operations for the whole process.

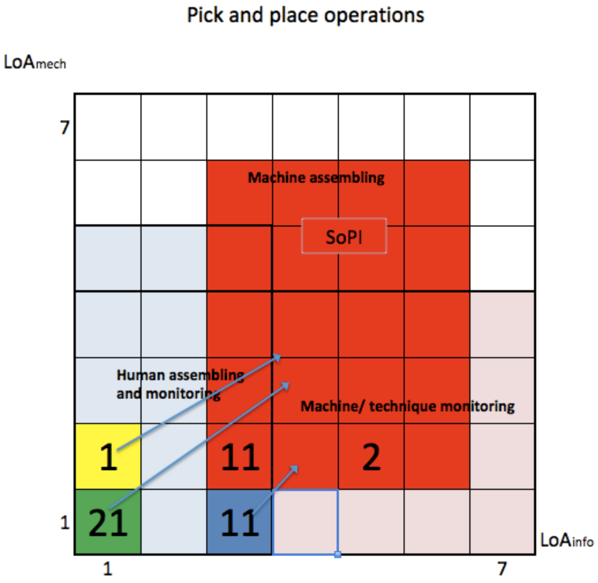


Figure 20. The SoPI for the pick and place operations.

4.6 Case 1 - The minimal investment approach

For the minimal investment approach the goal was mainly to keep as much as possible of the current equipment in the assembly process and to find innovative ways to improve the process with the perspective of achieving as much as possible with as little as possible. This solution may look very similar to the current process on glance, but with just a few changes the LoA levels have been raised and the flow in the process was improved.

The SoPI-analysis shows that the minimal level of automation for the process was finally placed at (5,5) for the mechanical operations and (2,3) for the rest of the operations. Through observations it was concluded that the machines performing the mechanical operations today do so in an acceptable fashion. To temper with this setup, or to invest in new equipment in these areas would bring large investment costs compared to focusing on the pick and place operations. Therefore the improvements are exclusive to this area of the process. The final placement of the solution for the process in terms of LoA is shown in figure 21.

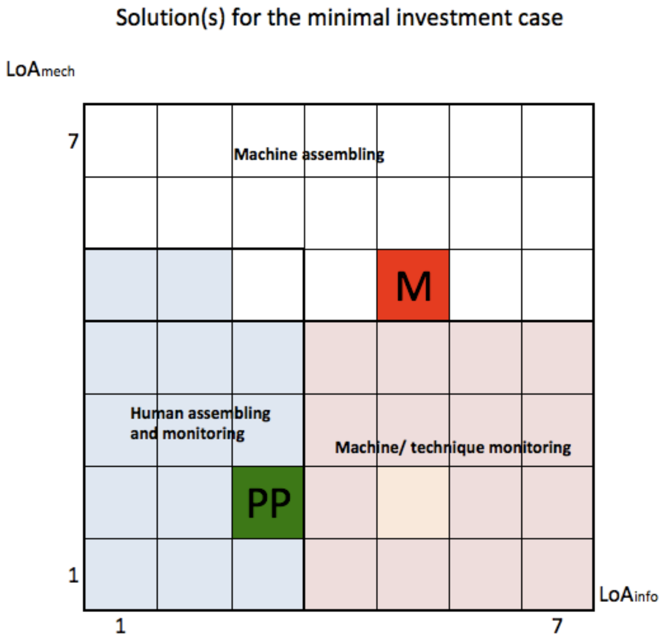


Figure 21. LoA for case one. “PP” refers to the pick and place operations and “M” refers to the mechanical operations.

4.6.1 Cognitive improvements

The first major improvement focuses on raising the cognitive LoA-levels of all “pick and place” operations to the third level. This was achieved by implementing the television screens explained in detail in chapter 4.4. However there are two operations that occupy the (2,5) level in the LoA-matrix due to a pick-by-light system. This feature is unchanged and subsequently the LoA for these two operations stays the same as well.

4.6.2 Mechanical improvements

To raise the mechanical level of automation to the second tier a number of different improvements were suggested. All of these solutions have in common that they are all mechanical fixtures of some kind to different parts of the product. This was due to the fact that static hand tools in the sense of tools from a toolbox, e.g. screwdrivers, hammers etc. were unnecessary in these kinds of operations. A fixture for a certain part is a different kind of static hand tool deemed appropriate for this situation.

A number of the concepts behind these fixtures chosen for implementation in the STAD assembly line were directly lifted from the assembly line of the COMPACT at IMI Hydronic Engineering. These fixtures include the “pipe-fixture for O-rings” shown in figure 22, and the fixture for springs delivered directly from the supplier shown in figure 23.

Figure 22. A type of pipe-fixture for O-rings.

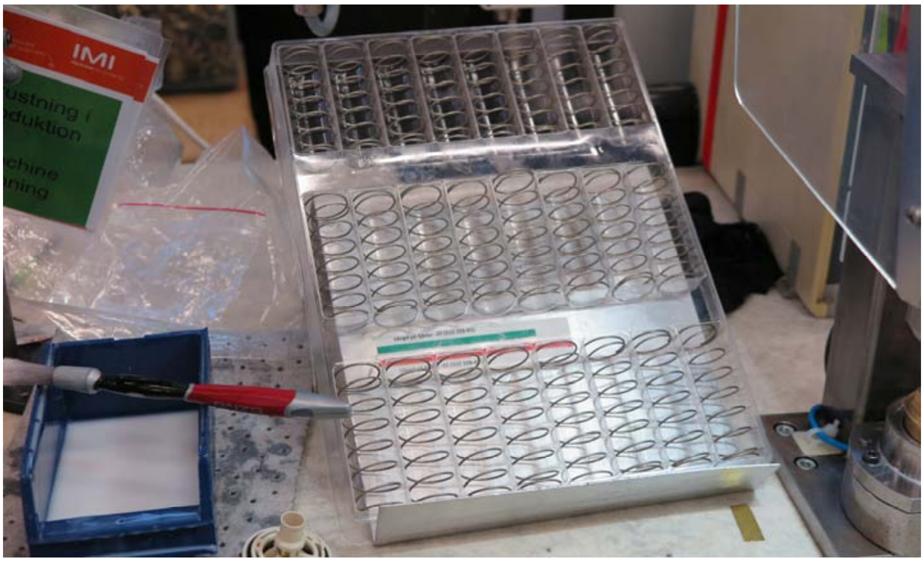


Figure 23. Box-fixture coming direct from the material supplier.

These concepts were also applied on numerous other components. A pipe-fixture was implemented for the PTFE washer and the O-ring in the second station These fixtures can come in different sizes to fit many types of components. Box-fixtures similar to the one found in figure 23 were also implemented on a range of other components. This improvement presumes other suppliers together with in-house material handlers can satisfy this demand. The components placed in box-fixtures are:

- Spindle
- Bonnet body
- Cone body
- Body
- Hand wheel
- Protective covers

Another set of fixtures is magazine type fixtures that are continually refilled by one or more operators responsible for the assembly cell. The magazine feeds the assembly operator with the desired part at the corresponding station. The components that adopt this system are:

- Measuring points
- Capholders

The last set of fixture is plastic fixtures that can be made in-house by 3D-printers or with cutting machines. This solution is applied between station one and two by placing these plastic fixtures specifically designed to fit the bonnet to be handed over to the next station with the cone part facing upwards. This solution is also applied to the table of station two. This is to give the house a fixture while assembling the bonnet and measuring points.

The track between station two and three was also tweaked. The idea was to implement a rail in the current track so that the house only could be sent one way to the next station instead of in an unorganized fashion. If needed, a rolling track could also be installed if the friction between house and track turns out to be a problem.

4.6.3 Balancing improvements

Based on the fact that there are problems in the current assembly process regarding balancing of tasks, wait between operations etc, along with the bottleneck operation being identified as the leakage test the in first part of the project a decision was made to line balance the process. In this case all of the operations after the leakage test apart from placing the body on the track were moved to station three (2.24-2.27 in the current state HTA).

As the ID insert was removed from the product in the DFA-phase of the first part of the project, a new solution for the branding of the product type and size was needed to keep the original function of the product. In this case, that solution is transferred to the packaging part of the process in the form of a basic sticker that the operator places on the same spot on the hand-wheel the marking is today.

To further balance the flow of the process the static machine mounting the hand-wheel was altered to be able to press one hand-wheel at a time. This makes the station come closer to a one-piece flow assembly process.

4.6.4 Result

To get an understanding of how the process has changed after implementation of the improvements discussed in this chapter a layout suggestion is shown in figure 24. The layout is based on the same three stations and machines used in the current assembly.

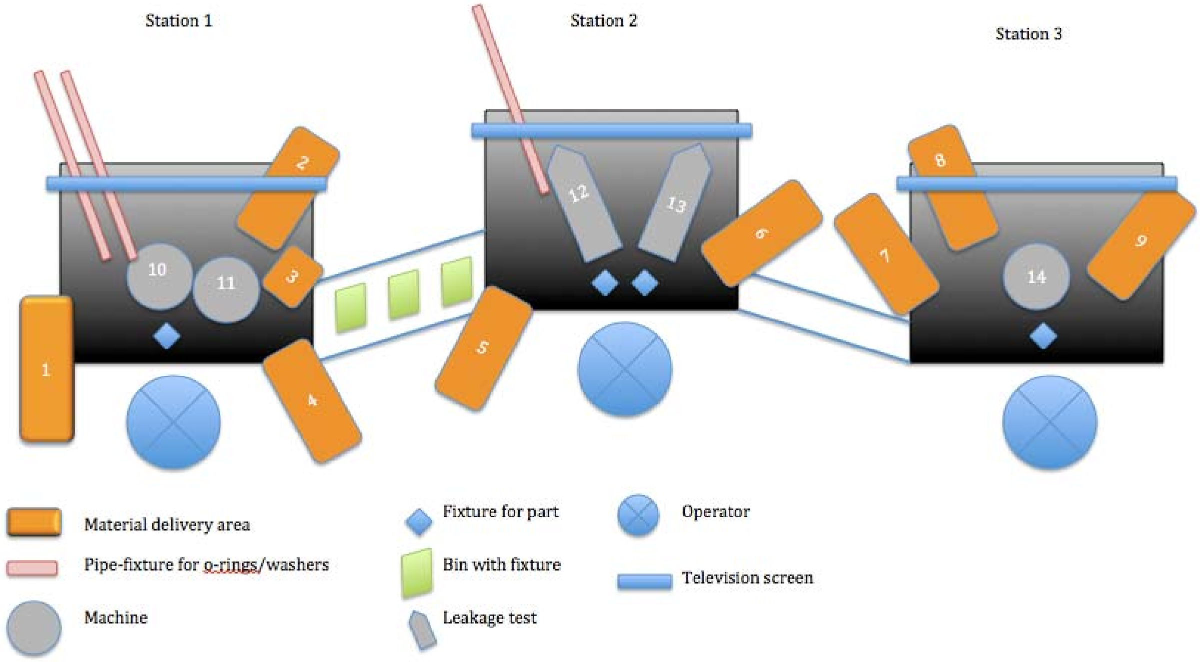


Figure 24. A concept layout of the first case.

A list explaining the components of the process in a more detailed way was compiled:

1. Fixture-bin for spindle
2. Fixture-bin for cone body
3. Fixture-bin for spring
4. Fixture-bin for bonnet
5. Fixture-bin for body
6. Magazine fixture for measuring points
7. Fixture-bin for protective cover
8. Fixture-bin for hand-wheel
9. Magazine fixture for capholders
10. Pressing machine
11. Screwing machine
12. Machine for leakage-test
13. Machine for leakage-test
14. Pressing machine

A new HTA for this case can be found in appendix D. This version further reduced the required tasks in the process to a total of 56.

In this case the cycle time of the assembly process was reduced from the original 37,7 seconds to 28,1 seconds, with the leakage-test operations still being the bottleneck. The full cycle time analysis is shown in figure 25.

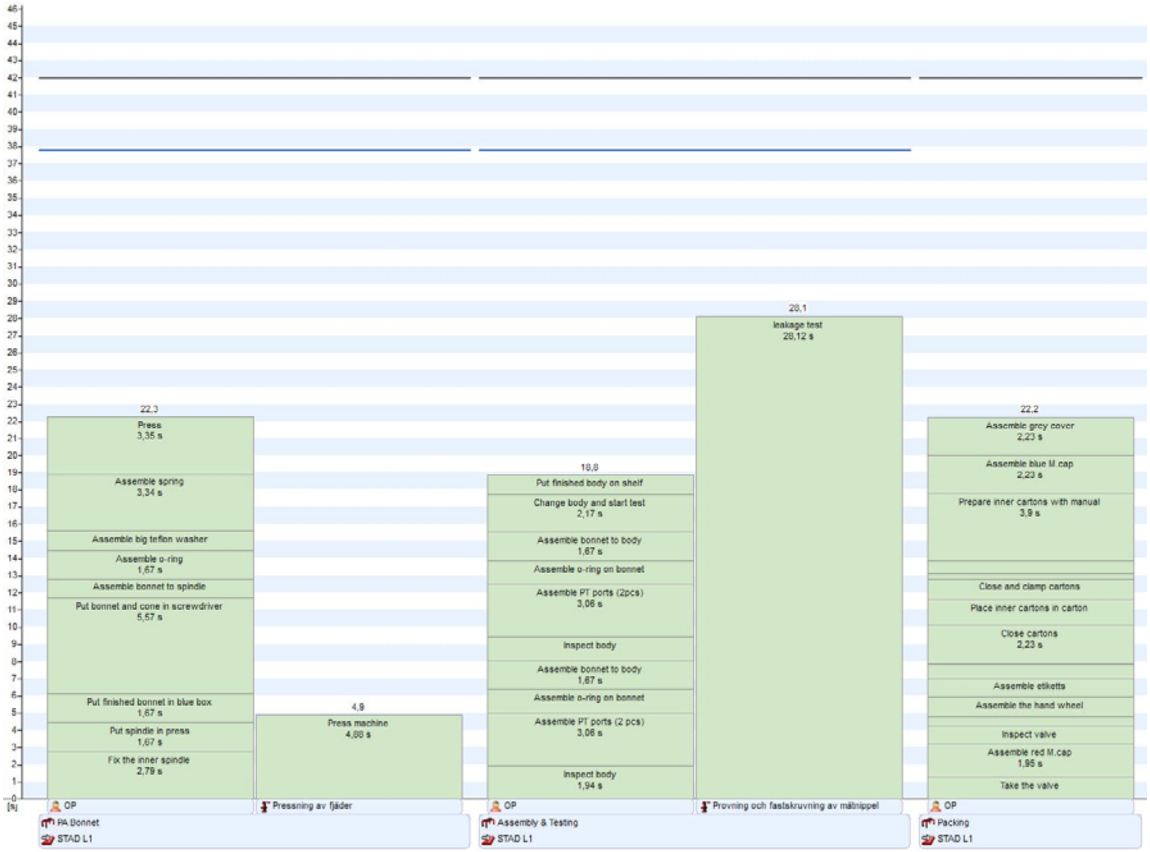


Figure 25. Analysis of the cycle time for case one through Avix. Note that the difference in cycle time for the stations (excluding the leakage test) now only differs four seconds.

4.6.5 Levels of automation

The goal of raising all the pick and place operations to a LoA of (2,3) was achieved in almost all operations. The only exception to this is the operations that start the different machines in the process. The reason it remains on the original LoA is because it was deemed unsafe to try to automate this process while the most of the work is still handled by an operator. The final LoA are showed in figure 26.

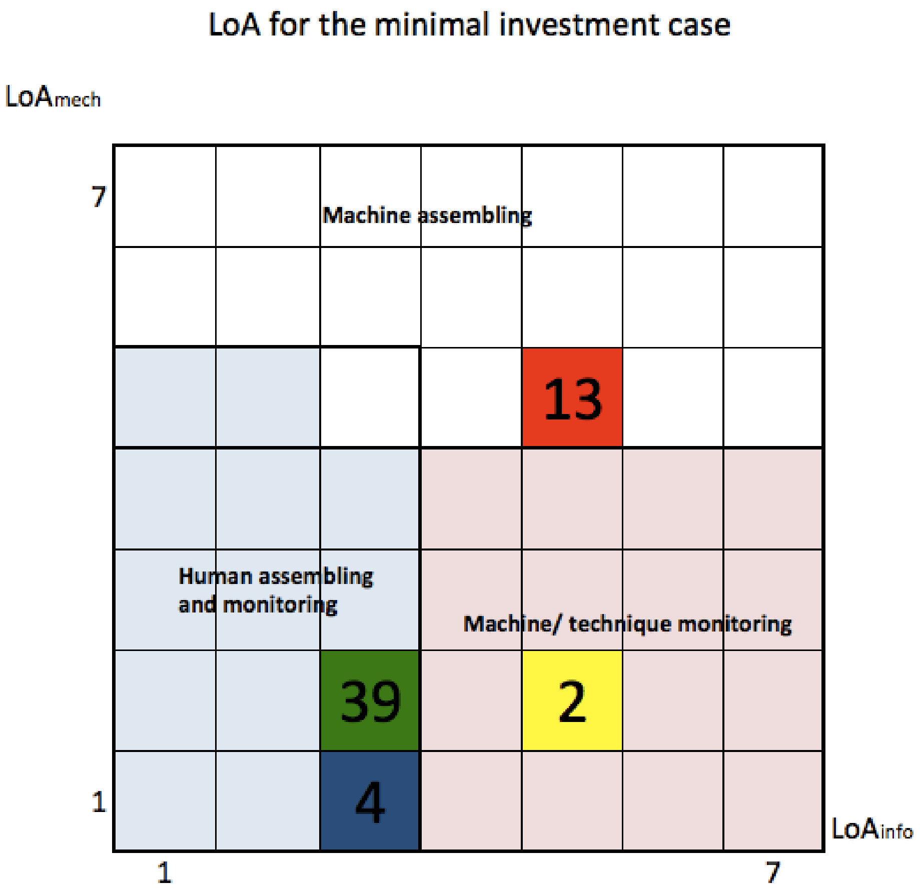


Figure 26. The final LoA for case one.

4.7 Case 2 - The fully automated approach

This approach was more focused on finding equipment and processes that work than on quantifying every operation on the same LoA. An example of this is the operation of fitting the small O-ring into position on the spindle. This part was deemed unfit to be assembled by a flexible robot and thus the operation was chosen to be done by a static machine with an alarm system, reaching a LoA of (5,5). Other operations were improved by having a flexible robot with force control sensors, and thus reached to a LoA of (6,6). Because of this, the process has “several solutions” in that some operations occupy different spaces in the LoA-matrix.

The fully automated solution of the process raises every individual operation to a LoA found in the to the upper 3x3 corner of the LoA-matrix. In the SoPI-analysis it was deemed unrealistic to implement a system that would fulfil a completely autonomous LoA, namely a solution located in the (7,7) space of the matrix. With the equipment and specifications of the product in mind the solution was changed from the traditional 1x1 box to a 2x2 box set between (5,5) and (6,6) in the LoA-matrix shown in figure 27.

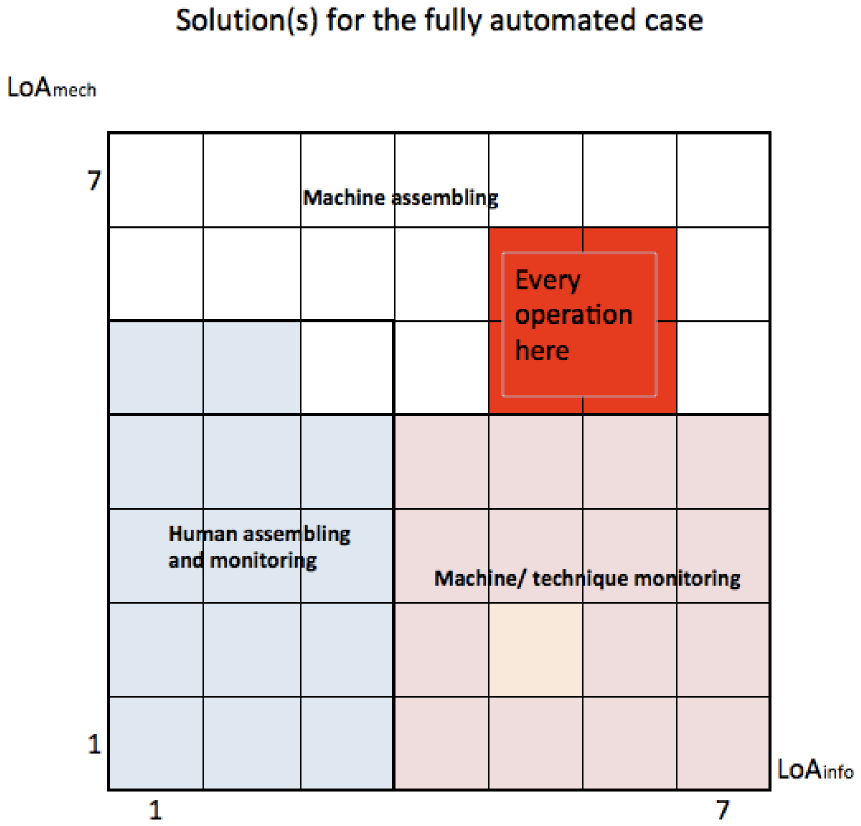


Figure 27. The solution-square for case two.

4.7.1 Equipment

This case is heavily dependent on equipment for its solutions. All equipment invested in is listed in this chapter and how it affects different areas is shown in forthcoming chapters. The equipment included in this case is as follows:

- 4 UR robots
- 3 SCARA robots
- 3 static machines
- 1 Motoman SDA5
- 4 Vision systems
- 4 Leakage test machines
- 7 Feeder-systems
- 1 Laser marking system

Vibratory-bowl feeders were used in six of the seven feeder-systems. The only exception was the feeder-system for the spring. It was determined that all other parts that needed to be fed could do so with a simple orienting-device in the feeder specifically designed to the corresponding part. In the case with the spring it was not deemed to be as easy to do this. As a solution it was determined to use a magnetic-disc feeder. The concept behind such a machine is showed in figure 28.

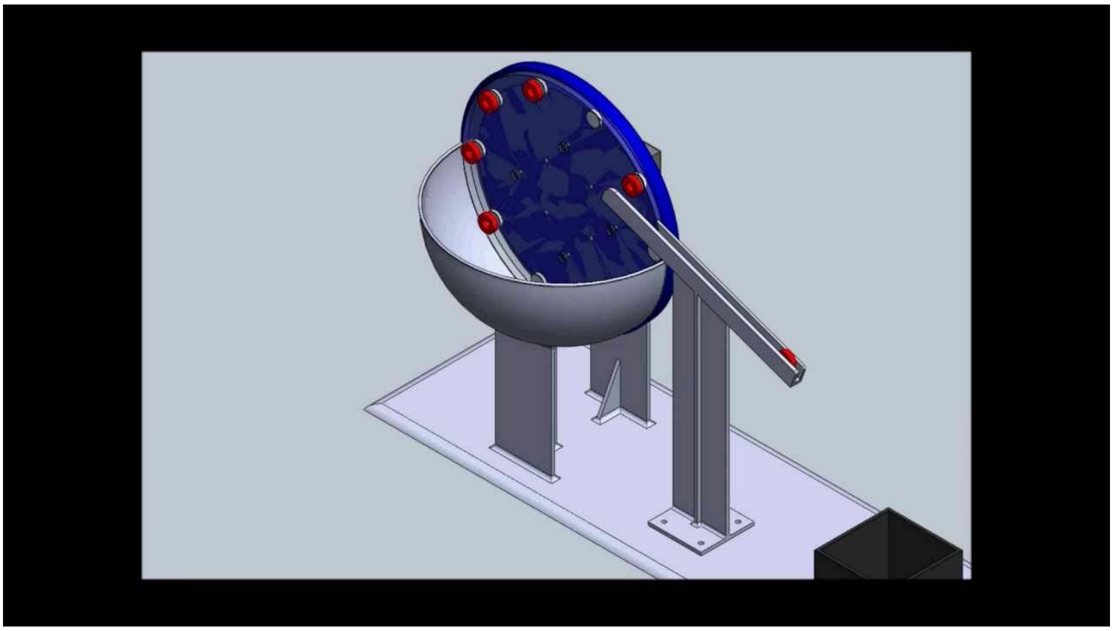


Figure 28. A concept construction of a magnetic-disc feeder. The grey circles on the wheel represent magnetic areas. The red circles represent picked up components.

The UR-robots usually come in three different sizes named after payload capacity. Today a customer can choose from the UR3, UR5 and UR10. The number in the name refers to the amount of kilograms the robot can operate with. Aside from weight, the operative radius for the robot also differs. In this approach it was estimated that a UR3 would complete all the desired tasks. The UR3 is shown in figure 29.

Figure 29. A UR3 robot.

The Motoman SDA5 is a dual-armed flexible robot. This robot in particular was chosen to handle the many pick and place operations in the early stages of the assembly process to get an even flow in the assembly. In a similar fashion with the UR robots it was estimated that the SDA5 would complete all its tasks, although there is a bigger version of the same robot called SDA10. The SDA is shown in figure 30.

Figure 30. Showing a Motoman model SDA.

The static machines are specifically designed for its corresponding tasks. A simple screwing tool at the first station that is connected to the centre pillar will perform the screwing operations between the spindle and the cone body. The O-rings will be mounted on the spindle using a type of pressing machine that will be similar to the pressing machine that mounts the O-ring on the pre-setting screw today in Poland. Finally the pressing machine designed to press the spring will also look similar to the one used in the current assembly.

Additional leakage-testing machines were invested in due to the fact that it is the bottleneck operation of the assembly. To further decrease the cycle time of this machine, robots operating on the rotary table performed the tasks of screwing the bonnet and the measuring points into the body.

Four vision systems were implemented in the solution. Three of these are connected to the Motoman SDA5 in the first station of the assembly. The last system is connected to the UR robot tasked with grabbing and pressing the hand-wheels on the bonnet.

4.7.2 Cognitive improvements

Most of the increase to the cognitive LoA came integrated in the robotics equipment, for example force control sensors in all UR, Motoman and SCARA robots. This results in a number of operations being located on the sixth level of cognitive LoA. In some cases this LoA was also reached through integration with a vision system or by implementing a feeder for orientation.

A raise in cognitive LoA was also achieved for every one of the leakage-test machines. This was done by connecting the current alarm system, which can detect what type of leakage/failure is present in a particular product, to the UR robot responsible for this area of the process. The robot is then programmed to place the defect part in one of a number of special tracks, each one reserved for products of that particular defect. A similar solution was observed both at CEJN and in the assembly of the COMPACT-valve and is shown in figure 31. This also raised the cognitive LoA to the sixth tier.

Figure 31. Escapement-tracks for different kinds of product defects.

Modern robots also come with the ability to be connected to alarm systems through I/O communication. In this case such a system is present throughout the whole process resulting in a minimal cognitive LoA of five. The rest of the equipment, i.e. static machines, transportation devices etc. are also presumably connected to this alarm system.

4.7.3 Mechanical improvements

Mechanical improvements were done mainly by investment in robotic equipment. This case consists of three different flexible robots. All operations affected by this equipment subsequently reach a mechanical LoA of six.

The solution also consists of three static machines. One for screwing the spindle into the cone body, one for pressing the O-ring into the spindle and the last one presses the spring into the bonnet. The operations done by these machines all reach a mechanical LoA of five.

Operations done by a feeder-system were also put on the same mechanical LoA.

The laser marking system was also estimated to have a mechanical LoA of five.

4.7.4 Result

The layout for the process was completely changed from the original setup. Based on relative size and operating space of the equipment the new layout is shown in figure 32 along with en explanative figure, number 33.

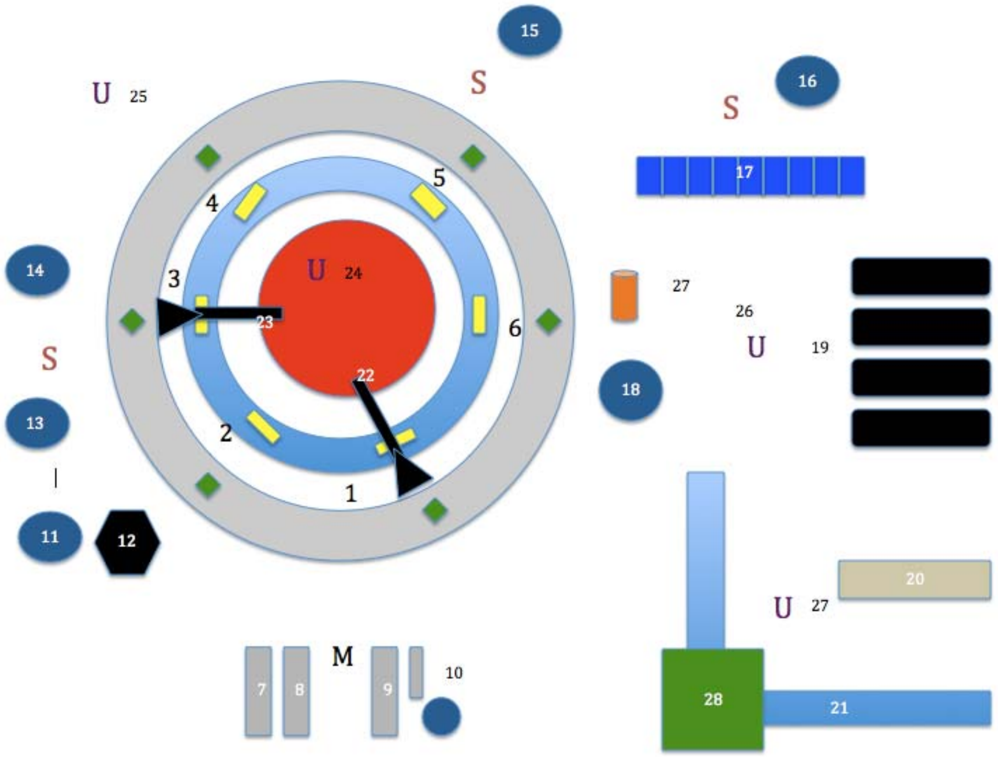


Figure 32. A concept layout for case two.

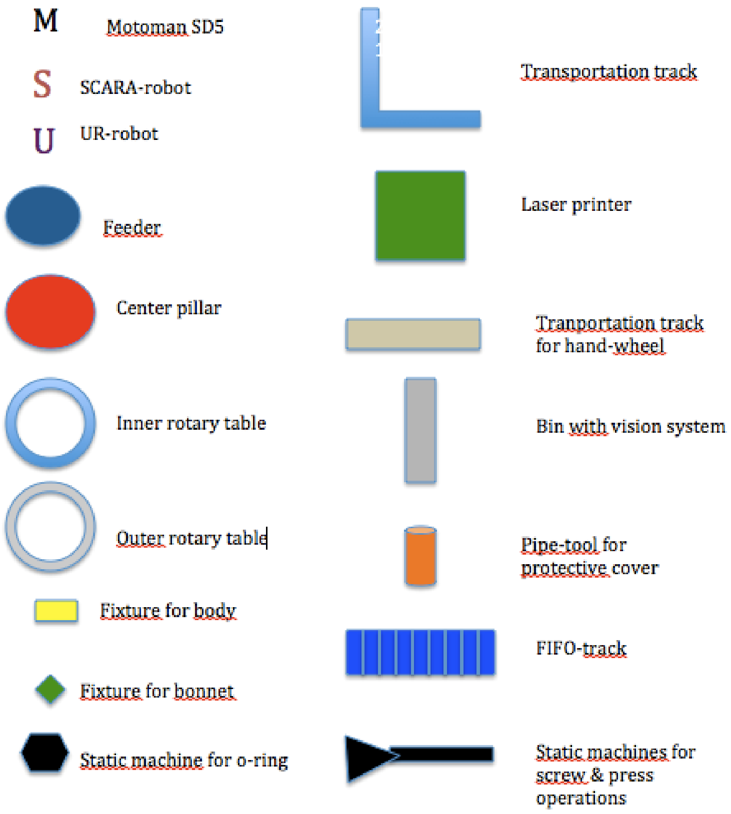


Figure 33. An explanative appurtenant figure to case two.

To further understand every piece of equipment, station and the corresponding operations and actions a detailed list following the numbering system in figure 32 is shown below:

1. Station one of the rotary table setup. Every one of these stations (1-6) has its corresponding fixture for both the house (on the inner rotary table) and bonnet (found on the outer rotary table). In this station a cone body followed by a spindle is placed in the outer fixture by the Motoman-robot. A static machine screws the spindle and cone body together.
2. In station two the O-ring is placed on the spindle by a static machine. The Motoman-robot then places the bonnet on the same fixture. The Motoman also places a body in the inner fixture.
3. At station three a SCARA-robot places both the PTFE washer and spring in the bonnet. A static machine then performs a pressing operation on the spring.
4. The UR-robot located at station five takes the bonnet and screws it into the body located on the inner fixture.
5. The inner fixtures are fitted with a tilting contraption that is activated in station five, positioning the measure point threads on the house in a vertical position. This is done to enable the SCARA-robot to pick two measuring points and subsequently screw them into position.
6. The tilting position is still held at station six. At this station a pipe-tool designed to mount a protective cover on one measuring point performs its

action. A UR-robot also lifts the partly assembled product out of the inner fixture and places it on the FIFO-track.

7. An integrated delivery station found in several stations (7-9). The station consists of a transportation track on which components can be put on in a disorderly fashion, which transports the products to a bin that has a rumbling-function for re-orientation along with a vision system. The component in this station is the body.
8. Delivery station for the bonnet.
9. Delivery station for the cone body.
10. A delivery station for the spindle. This station consists of a vibratory bowl feeder connected to a delivery track.
11. Feeder for O-rings.
12. Static machine for fitting the O-rings onto the spindle.
13. Feeder for PTFE washers.
14. Feeder for springs.
15. Feeder for measuring points.
16. Feeder for capholders.
17. FIFO-track that acts as a buffer for products ready to be put in a leakage-test machine.
18. Feeder for protective cover.
19. A station consisting of four leakage-test machines.
20. A transportation track on which an operator sets a number of hand-wheels to be delivered to the UR-robot in the station. The track and the robot are both integrated with a vision system.
21. A transportation track for products going in to the laser printing station and out of the assembly process as finished products ready for packaging.
22. Static machine designed to screw the spindle into the cone body. The machine is mounted on the centre pillar.
23. Static machine designed to press the spindle into the bonnet. The machine is mounted to the centre pillar.
24. UR-robot designed to paste a sealing material on the body. This operation replaces the operations of putting an O-ring on the bonnet found in previous approaches. An example of how such an operation can look is showed in figure 34.
25. UR-robot designed to screw the bonnet into the body.
26. UR-robot that moves the product between the inner fixture, FIFO-track, leakage-test and the final transportation track.
27. UR-robot designed to grab the hand-wheel from the transportation track and press it onto the bonnet.
28. Laser-printing station. The product is moved through this station by the same transportation track found in the previous stations.

The HTA based on this case can be found in appendix E. This HTA does not recognize the operations of moving the product that are carried out by the rotary table and transportation tracks. In this case the total number of operations was further decreased to 40.

The cycle time for this case was evaluated to be around eleven seconds.

Figure 34. A pasting operation performed by a UR-robot.

4.7.5 Levels of automation

The goal of reaching a LoA inside the solution square shown in figure 27 for all operations was reached with this approach. The final LoA of this case is shown in figure 35.

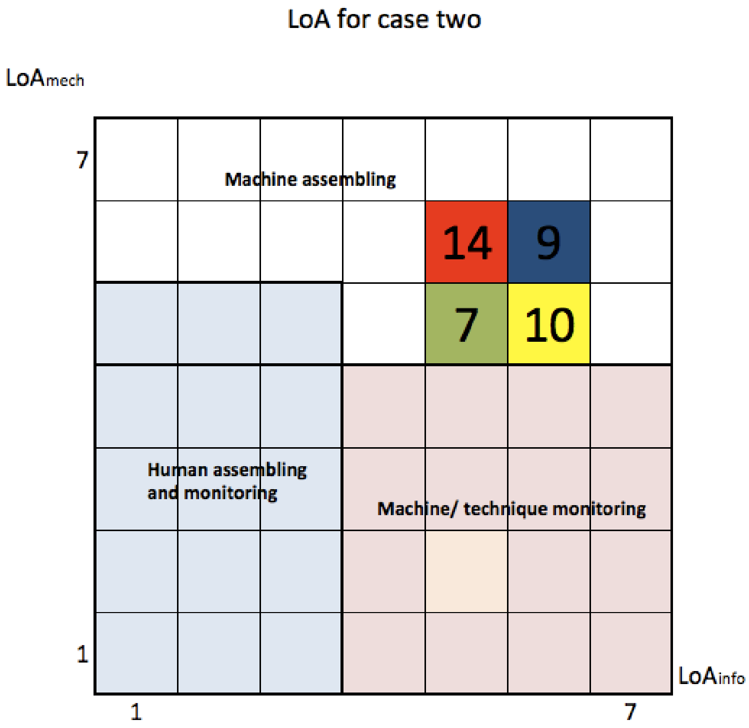


Figure 35. The LoA-matrix for case two.

DISCUSSION

In this chapter subjects of the empirics will be discussed and analyzed to gain a better understanding of the achieved results. The discussion is also discusses the theory chapter, although not in every specific case.

5.1 Assembly parameters

In the process of finding solutions for the assembly process the main assembly parameters considered were effect on cycle time and the investment cost.

It was recognized that investment cost is an important factor in determining if the automation solution is viable. However calculations and information regarding this parameter are limited in the case descriptions. The reason behind this fact is that it proved extremely difficult to obtain reliable information about the investment cost of equipment, machines and tools without a lengthy, direct contact discussion with all the affected companies. Solid numbers of the kind deemed acceptable to include in the cases were only found in two instances throughout the whole project. The first is in two offers made to IMI Hydronic Engineering from two separate automation companies. The second is in the investment cost associated with the purchase of a new UR robot.

As the investment cost parameter proved difficult to evaluate, a shift in focus towards cycle time took place. The evaluation of cycle time for the different cases along with the current state did also see some problems. A part of this was due to the fact that the current assembly of the STAD is located in Poland, and therefore a comprehensive understanding of the cycle times for the process were difficult to correctly identify. The correct parameters were identified after some time through films from the assembly in Poland along with studying the assembly in Avix.

As the first case only saw an improvement in process flow by reduced components and higher LoA with basically the same equipment present today, the cycle time parameters for this case were done through Avix using the same base data as the current assembly mapping.

The equipment for the assembly process in the second case is radically different than that in the first case. This resulted in a challenge when posed to quantify any type of cycle time for the process, as the new equipment could not be tested in any way. The only piece of equipment that is the same from the original setup is the leakage test machines. These machines are also responsible for the bottleneck operations in both the current assembly and in the first case. Based on these facts the choice was made to evaluate a cycle time based on these machines. To reduce the bottleneck effects the operations of screwing both measure points along with the bonnet into the body was moved to the operations done on the rotary table. Along with investing in a total of four machines instead of two in the previous approaches the cycle time was reduced to roughly eleven seconds for the testing process. The rest of the concept layout is wholly based on this still being the bottleneck of the whole assembly. The number of stations on the rotary table, how many operations are done at each station and the equipment for the tasks were all chosen to keep all operations apart from the testing under eleven seconds. This resulted in the cycle time for this theoretical concept being set at eleven seconds.

5.2 Workshop

By studying the two solutions for the process it is clear that not all of the ideas in the workshop were included, and additional ideas that were not invented during the workshop did make it in the final solutions.

Most of the ideas generated by the workshop were of a high quality and were applicable in some measure in the assembly. These ideas were integrated in the solutions were it was deemed appropriate. However, some ideas did not see the same fate.

The biggest potential loss for a superior solution can be found in the second highest rated idea regarding leakage-testing the valves with helium instead of air. The engineers at the workshop judged this idea both possible and potentially revolutionizing for the assembly process, yet it was not included in any of the solutions. The reason behind this was broadly speaking a lack of information about the process. In trying to find answers regarding the possibility of implementation to the STAD assembly, along with important parameters such as cycle time, investment cost etc. simply researching the subject was not deemed credible enough of a source. The research concluded that the process needs to be highly adapted to every specific product in mind for implementation. This meant that the parameters and final outcome of implementing such an idea could not be reached without an extensive dialogue with the affected company. This was not possible due to time constrains. It should also be noted that several companies in that part of the industry were approached through both email and over the phone but none responded.

Idea number seven in the list found in chapter 4.4 was also not implemented. Such an alarm system for picking operations would increase the cognitive LoA of those operations to the fifth level. A brainstorming session was held as if this idea was feasible to implement, but a concrete idea for implantation could not be reached with the minimal-investment perspective. Along with the fact that the solution for this case regarding these kinds of operations was set to a LoA of (2,3), the idea was discarded. In the second case an automatic alarm system was implemented throughout the whole system, making this idea obsolete.

5.3 Levels of automation

Traditionally the “new” solution of a process should have all its operations on the same LoA. Where this “solution-square” is located within the LoA-matrix is based on the SoPI. The reason behind the two operations located at (2,5) in figure 26 were left alone while redesigning the process was that it was deemed that the pick-by-light system already in place helped the operator to perform the current task.

5.4 The square of possible improvements

In the evaluation of the possible solutions from the SoPI, especially in a case based approach like the one in chapter four, there are sometimes incentives to adopt a perspective of a corner-case approach. This method finds several solutions in the respective corner of the SoPI, and tries to adopt that solution to the process. This is done to gain additional perspectives on how the process can be changed. This was initially a goal with the project, however it was later changed due to time constrains. The focus shifted from a broad solution perspective to a more comprehensive evaluation of fewer cases. A part of this decision was the argument “quality over quantity”. Nevertheless, it is recommended to use this method in case-based approaches of studying the SoPI, and the method itself was adoptable in this specific situation.

Traditionally, the solution for a process that comes out of studying a SoPI is only a 1x1-square in the matrix. This means that the solution aims for all operations to be placed at the same physical LoA and the same cognitive LoA. In the second case the chosen solution clearly differs from this traditional definition. This was in part because of the initial approach of dividing the process based on the type of work that had to be done. This approach did not work perfectly in the construction of the SoPI in the traditional way, but nevertheless it was deemed that the choice of creating a 2x2 SoPI worked for this specific process and was consistent with the rest of the project.

5.5 The minimal investment case

Apart from the decrease in cycle time from the current assembly, this solution also affects the quality of products that flow through the process. Because of the rise in mechanical LoA by applying fixtures to almost every operation along with raising the cognitive LoA through detailed instructions from television screens an argument can be made that the process will have a superior quality output compared to the current assembly. The quality of the products will not become better because of these implementations, however the quality will become more even. This in turn means that the cause of defect products is easier to locate and prevent from happening again.

It is mentioned in chapter 4.6.2 that it is presumed that in-house suppliers of material can deliver this material in fixtures to the assembly stations. This solution is practically not expensive to implement and results not only in a higher quality process for the assembly, but for logistics as well. In the current logistic process of supplying the assembly stations with material the number of components in a bin differs with every such operation, according to Bladh and Sönegård (2015). This problem can be solved by this solution.

This suggestion could be implemented by investing in cheap plastic fixtures applicable to the containers already in place at the company. Therefore it is recommended that the box and pipe fixtures found in the same chapter be implemented throughout every possible process at IMI Hydronic Engineering.

5.6 The fully automated case

The argument made for the first case in chapter 5.5 that higher mechanical and cognitive LoA lead to a better process quality wise can be made in the second case as well. As the LoA in this case is increased even further, so will the quality of products in the process.

5.7 Equipment

Choosing the right equipment is always a challenge due to the many parameters and areas of operations affected. During the process of choosing equipment many arguments and brainstorming sessions led to a number of options for specific tasks being available. The reasons behind the choice of some equipment over others are discussed below.

5.7.1 The industrial robots

It should be highlighted that every decision connected to investing in an industrial robot in the second case was accompanied by a decision to go with the smallest (and cheapest) version of that robot. The argument behind this decision is that it was deemed possible to implement the smallest version of the robots according to the concept layout of the case. To minimize investment cost, this should be the initial perspective in the implementation of the solution, with reservations to increase the size of the robot if necessary.

In keeping with the company’s wishes for flexible and cheap robots for the automated assembly the UR robot came out as the winner for most of the operations. As the robot can be programmed physically by an operator that simply moves the robot to the desired position along with it’s many uses in assembly operations (gripping, moving, screwing, pressing etc.), the robot was deemed flexible enough. As the estimated price for such a robot today is 23 000 USD it was also deemed cheap. These specifications along with remaining parameters were discussed by Østergaard (2015). For the UR3 the operating range is a radius of 50 cm. This was also seen as an acceptable limit to the solution. However, if this proves to be a false assumption, the switch to a bigger model of the same robot can be done quite easily. The price for the bigger models are 35 000 USD for the UR5 and 45 000 USD for the UR10.

A Motoman SDA5 was also preferred for the first station of the automated assembly solution. A discussion was held regarding the choice of this robot or a dual UR cell, pictured in figure 36. The choice of the Motoman SDA5 over two UR robots was not entirely evaluated due to time constrains. However, the performance as well as the price of such a robot cell was deemed to be quite similar in both cases.

Figure 36. A dual UR5 robot cell.

To achieve the best flexibility possible in the fully automated case the choice of investing in SCARA-robots was done carefully as these kinds of robots do not qualify for the same level of flexibility as their UR or Motoman counterparts. Therefore, the choice of investing in a SCARA robot for a station was done exclusively in regard to components of the STAD that were of a universal size between different dimensions of the valve. To give an example, the O-ring that fits on the spindle is the same size in every version of the STAD, therefore a SCARA robot can be used for this operation and the process still maintains its flexibility. However the large O-ring that is fitted to the body is of different sizes depending on what version of the STAD is currently assembled, so the corresponding solution involves a UR robot that can be programmed to the corresponding sizes, and thus the level of flexibility is set to the same standard.

A third flexible robot in the same class of operational usefulness as the UR3 and Motoman SDA5 was also investigated. The third choice in the evaluation of these operations was the Baxter robot from Rethink Robotics. This robot is similar to the Motoman due to the fact that it has two operational arms. It has one significant advantage compared to the other two, being the fact that it is equipped with cameras in both of its arms that can act as vision systems for many operations, e.g. picking and placing parts. However it was quickly discarded from the list of options. This was due to the robot only having an effective payload capacity of 2.3 kilograms while the biggest size of the STAD valve; the STAD DN50 weighs 2.4 kilograms.

5.7.2 The feeder systems

In the process of choosing feeder systems for the parts in the assembly a discussion and brainstorming session was held for every one of the parts that would use a feeder system as its feeding and orienting solution. The idea was to fit the parts into a classic vibratory-bowl feeder system. This would mean that the only areas of these systems that would change between parts were the size of the bowl and the orienting system in the bowl. However, an easy and effective solution with this frame of mind could not be reached in regard to the springs, in great part due to its geometry. The brainstorming eventually led to the decision to implement a magnetic-disc feeder, as it was deemed compatible with the geometry of the spring, along with the fact that the spring is made of a ferromagnetic material. It is important to note that if a solution can be found for the geometry of the spring to fit in a classic vibratory-bowl feeder system such a system may well be implemented instead of the magnetic-disc feeder. A cost-comparison between these two system was not compiled due to time constrains.

5.7.3 Tools

Because of the fact that the geometry of the two capholders is identical it was decided that the SCARA robot responsible for pressing these details on the measuring points should be fitted with a tool that can grip two capholders out of the feeder track in one operation. Subsequently it will also place two capholders on the measuring point in the next operation. This will result in the number of operations being reduced by two.

The SCARA robot responsible for placing the PTFE washer and the spring into the bonnet in station two of the fully automated case will also have a special tool. In that case it was determined that this robot should be able to handle both parts due to their similarities in diameter and geometry. The spring places a constraint on the corresponding pick operation, as it needs to be picked in a certain way. This is because the spring is asymmetrical and needs to be placed in a certain way in the following operation. The PTFE washer is symmetrical and can be inserted in multiple ways, meaning that it does not place a constraint similar to the spring. If the spring would be symmetrical according to the lower end of the spring, the areas the tool needs to pick on corresponding parts would exactly match. This would mean that the same tool could be used for both pick and place operations without extra testing and calculations. As this is not the case today, the areas of the parts that the tool needs to pick differ slightly. It therefore becomes crucial to evaluate the choosing of this tool and to test it properly to make sure it will work with both parts. The most promising choice of tool was evaluated to be a vacuum-gripping tool. The reasoning behind this choice of tool is that this solution requires one less robot, thus minimizing investment cost.

5.8 Validity and reliability

Because every result in this project was checked according to the theory of that subject, along with numerous discussions with engineers at IMI Hydronic

Engineering who are experts in the areas under study, the conclusions and outcomes of the project have all been theoretically validated.

However, because of the nature of the project no physical validation has been established. Based on the fact that no tests or actual implementations of the suggested improvements have been made there is no guarantee that the suggestions will work as intended. To ensure the physical validity of this project physical testing of all redesigns and concepts must be done.

CONCLUSION

Based on the component structure and current assembly process it is deemed possible to automate the assembly process of the STAD. The STAD is suitable for an automated assembly transformation due to its high volume and moderate standardization between both dimensions in the product family and other products at IMI Hydronic Engineering.

Two cases based on equipment investment were compiled. One minimal investment approach that invested in:

- Television screens
- Pipe-fixtures
- Plastic fixtures for components
- Bin-fixtures for material supply
- Magazine fixtures
- Standardized tracks between stations

One fully automated assembly approach that invested in:

- 4 UR robots
- 3 SCARA robots
- 3 static machines
- 1 Motoman SDA5
- 4 Vision systems
- 4 Leakage test machines
- 7 Feeder-systems
- 1 Laser marking system

The minimal investment approach raised LoA for almost every pick and place operation to (2,3) by implementation of the equipment listed above.

A fully automated assembly process was created that is capable of assembling every dimension of the STAD product family along with crucial components found in other products.

The minimal investment case was capable of reducing the cycle time by 9,6 seconds from 37,7 to 28,1 seconds, resulting in a 25,4 % decrease in cycle time. It also raised the qualitative aspects of the process. The number of necessary operations decreased by 3, from 59 to 56. The majority of operations were qualified for a LoA of (2,3) or (5,5)

The fully automated case was capable of reducing the cycle time by 26,7 seconds from 37,7 to 11 seconds, resulting in a 70,8 % decrease in cycle time. It raised the qualitative aspects of the process even further than the first case. The number of necessary operations decreased by 19, from 59 to 40. Every operation in this process qualified for a LoA between (5,5) and (6,6).

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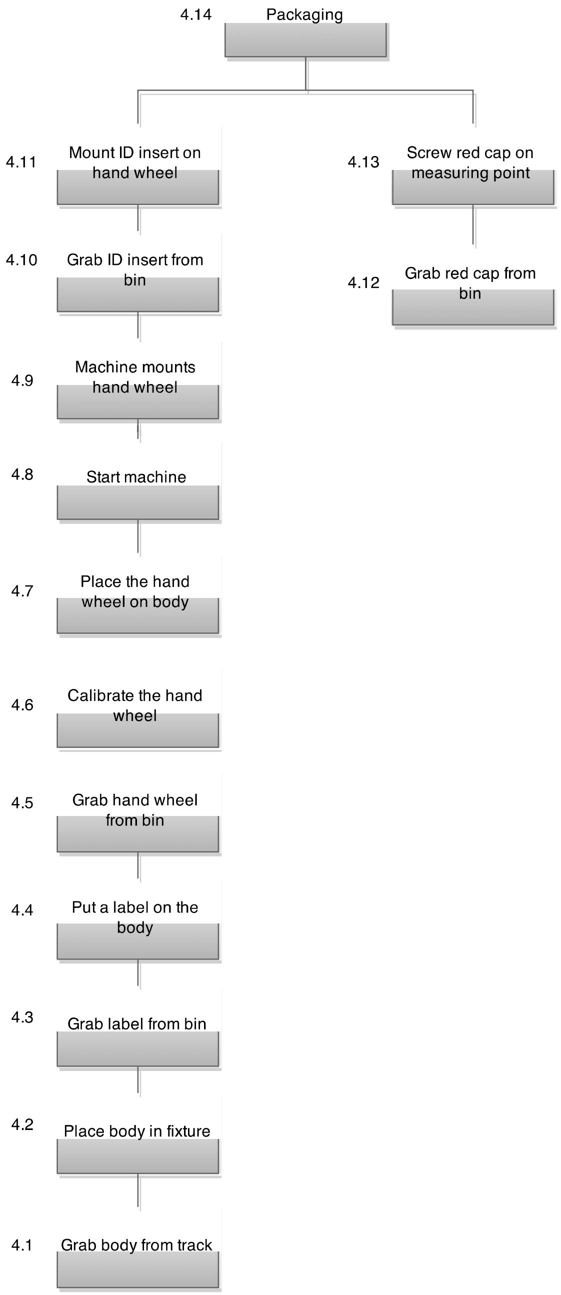
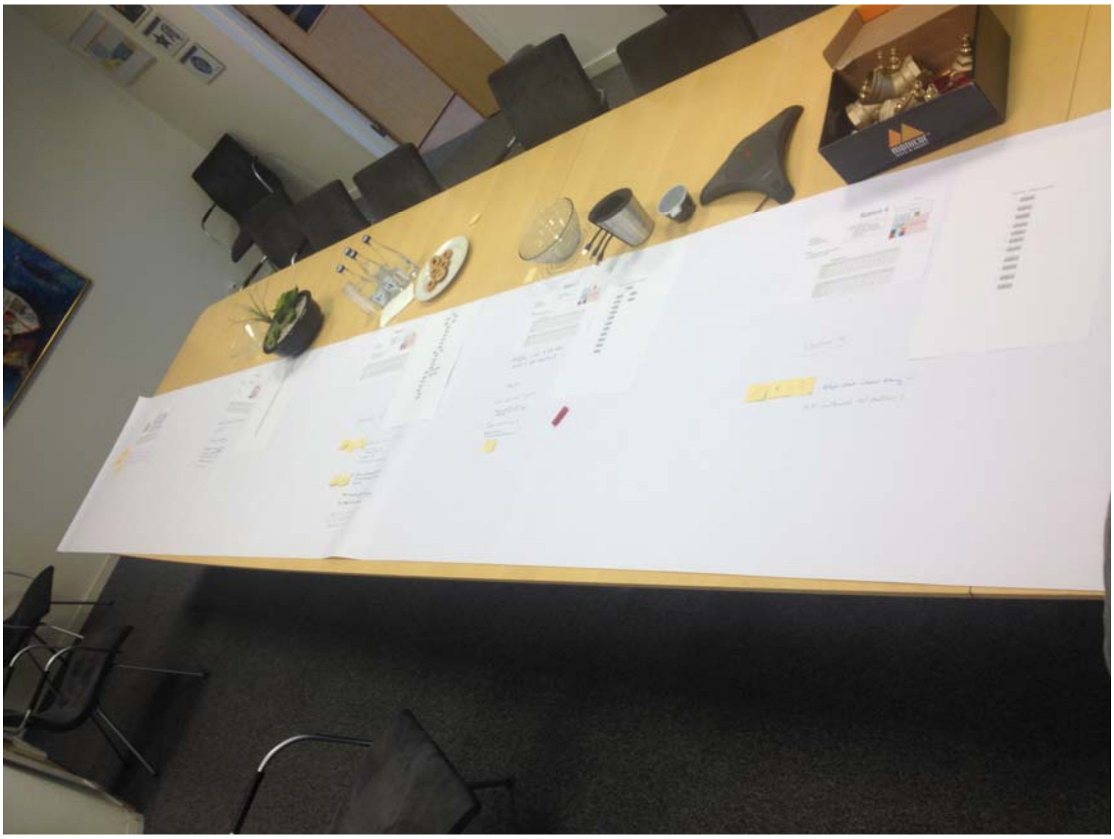
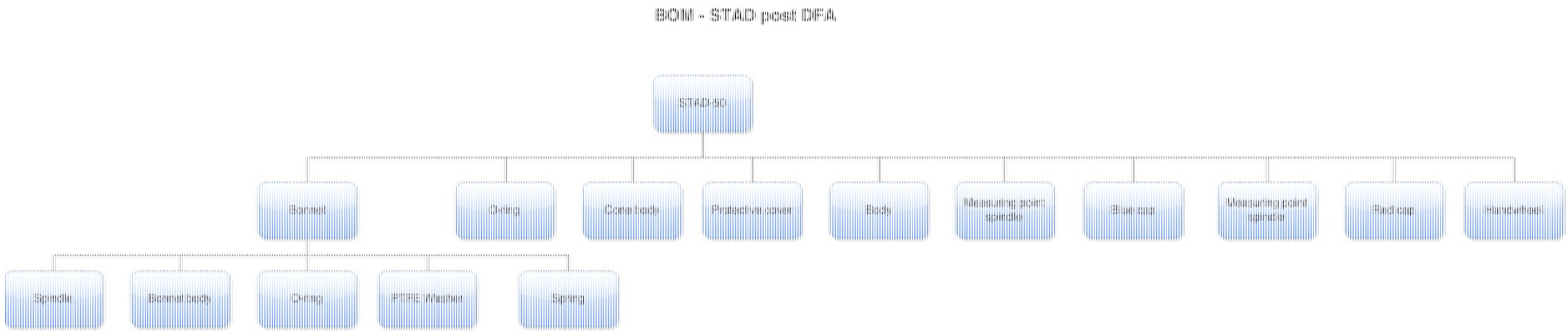
Appendix A – Workshop

Station four - Final assembly and packaging

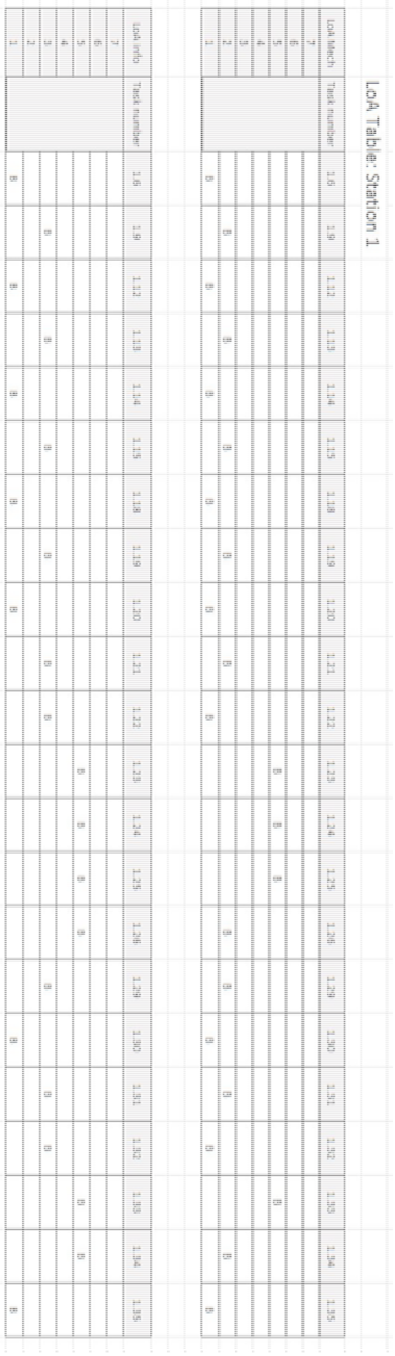




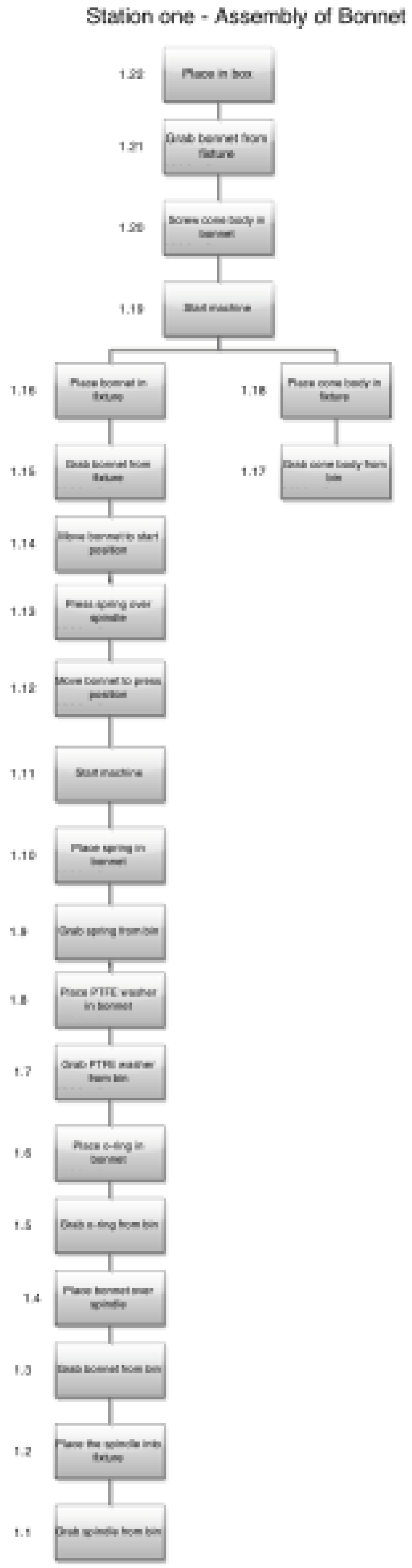
Appendix B – Bill of Materials

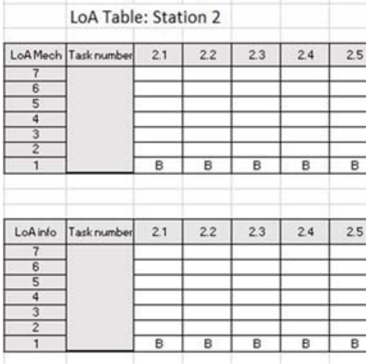


Appendix C – HTA for the current product



LoA Table: Station 1

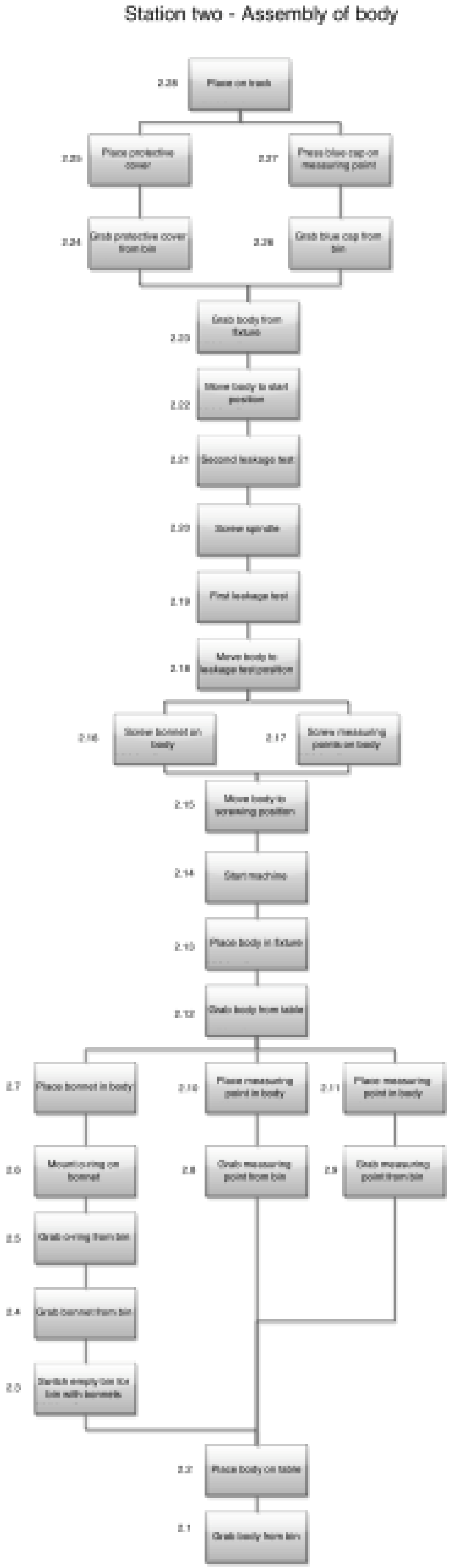




LoA Table: Station 2

LoA Mech	Task number	2.1	2.2	2.3	2.4	2.5
7						
6						
5						
4						
3						
2						
1		B	B	B	B	B

LoA info	Task number	2.1	2.2	2.3	2.4	2.5
7						
6						
5						
4						
3						
2						
1		B	B	B	B	B



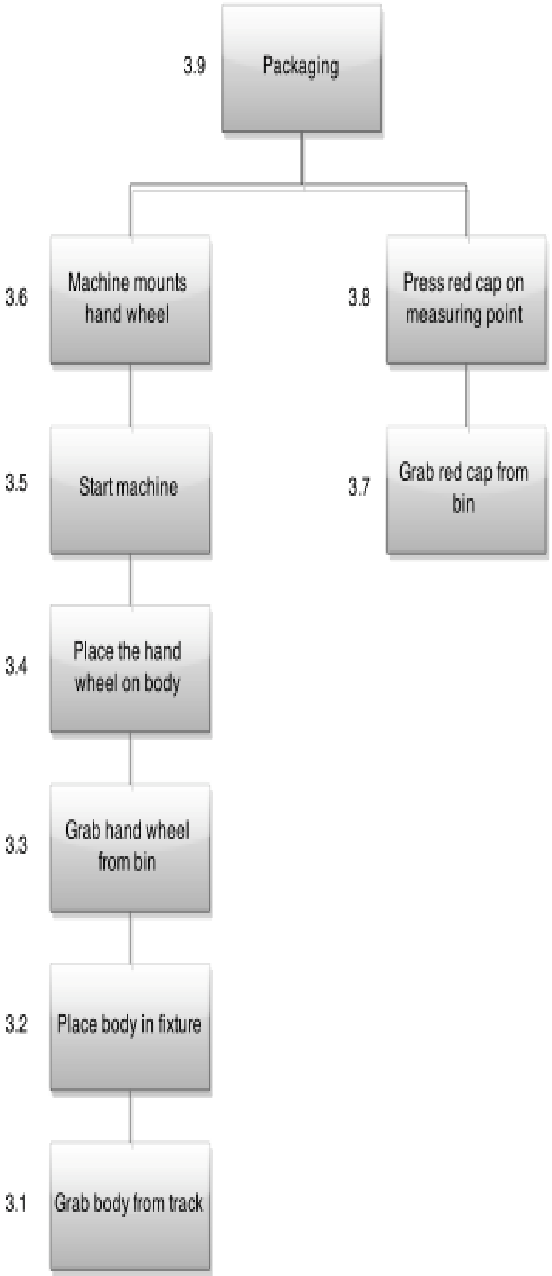
Station two - Assembly of body

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
7										
6										
5							B			
4										
3										
2			B		B					B
1		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
7										
6										
5							B			
4										
3			B		B	B			B	B
2										
1		B		B				B		

Station three - Final assembly and packaging



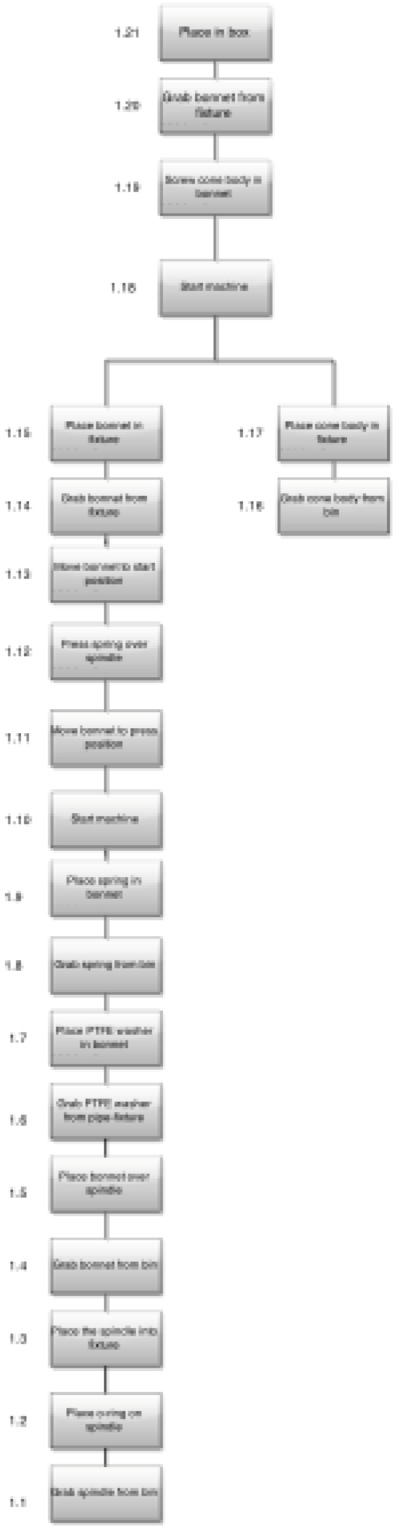
Appendix D – HTA for case one

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	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21
7																						
6																						
5												B	B	B						B		
4																						
3																						
2		B	B	B	B	B	B	B	B	B					B	B	B	B			B	B
1											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	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21
7																						
6																						
5												B	B	B						B		
4																						
3		B	B	B	B	B	B	B	B	B	B				B	B	B	B	B		B	B
2																						
1																						

Station one - Assembly of Bonnet

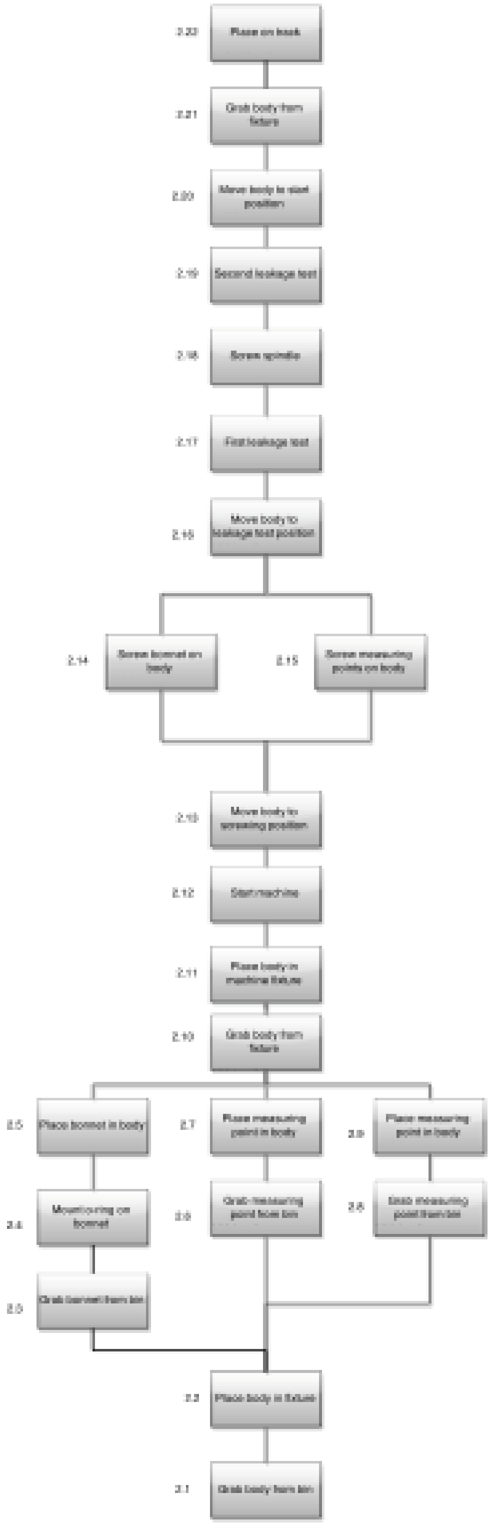


LoA Table: Station 2

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	2.19	2.20	2.21	2.22
7																							
6																							
5														B	B	B	B	B	B	B	B		
4																							
3																							
2		B	B	B	B	B	B	B	B	B	B	B										B	B
1													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	2.19	2.20	2.21	2.22
7																							
6																							
5														B	B	B	B	B	B	B	B		
4																							
3		B	B	B	B	B	B	B	B	B	B	B	B									B	B
2																							
1																							

Station two - Assembly of body

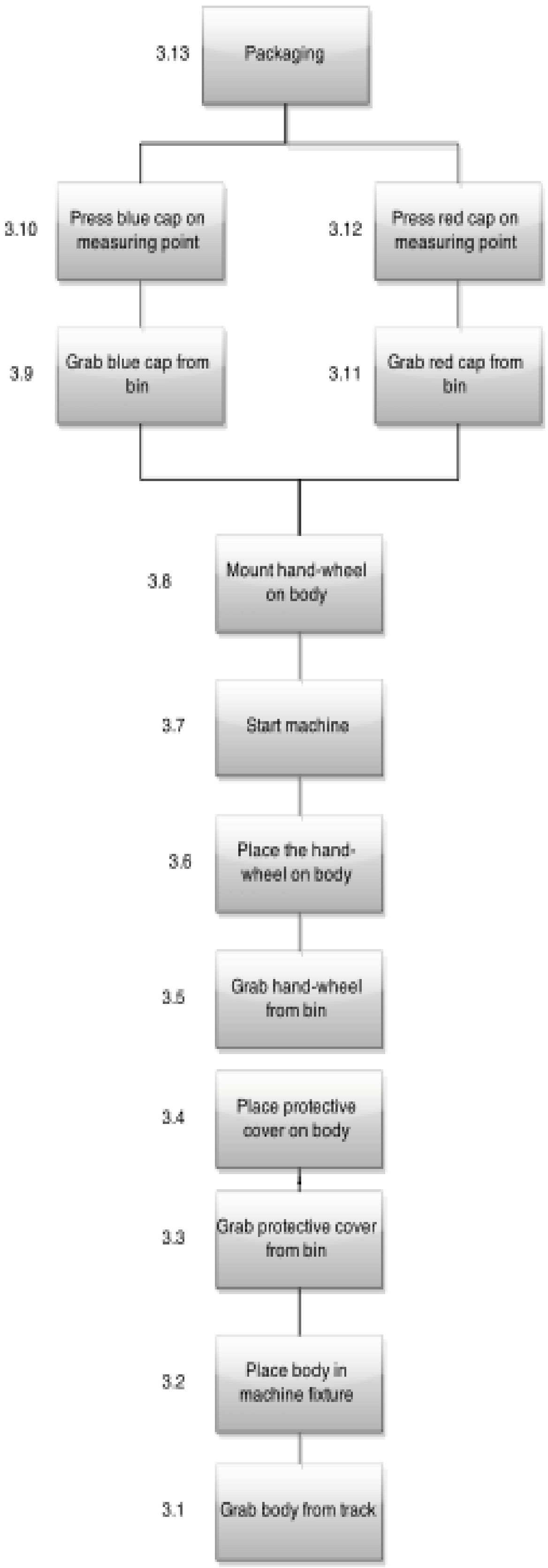


LoA Table: Station 3

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
7														
6														
5									B					
4														
3														
2		B	B	B	B	B	B			B	B	B	B	B
1								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
7														
6														
5									B					
4														
3		B	B	B	B	B	B	B		B	B	B	B	B
2														
1														

Station three - Final assembly and packaging



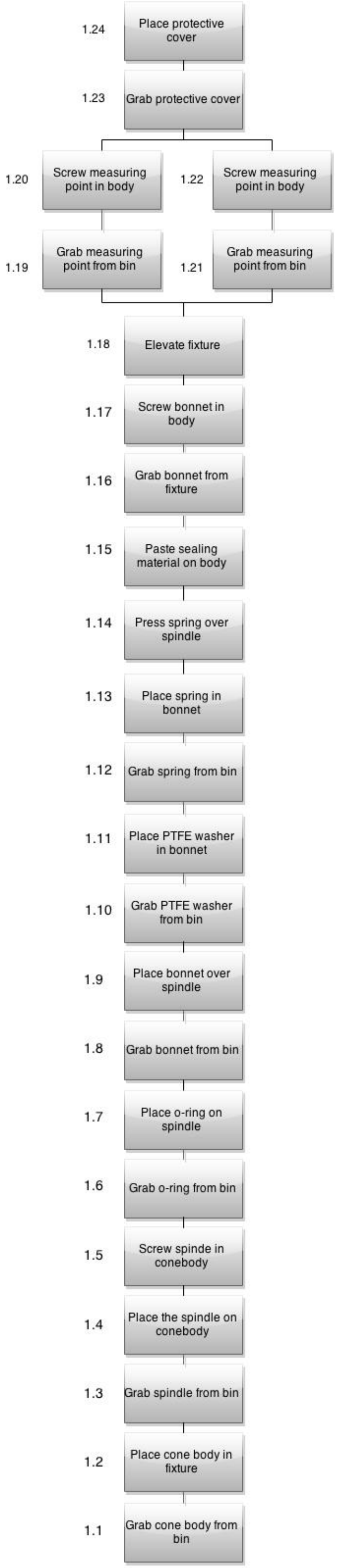
Appendix E – HTA for case two

LoA Table: Rotary table operations

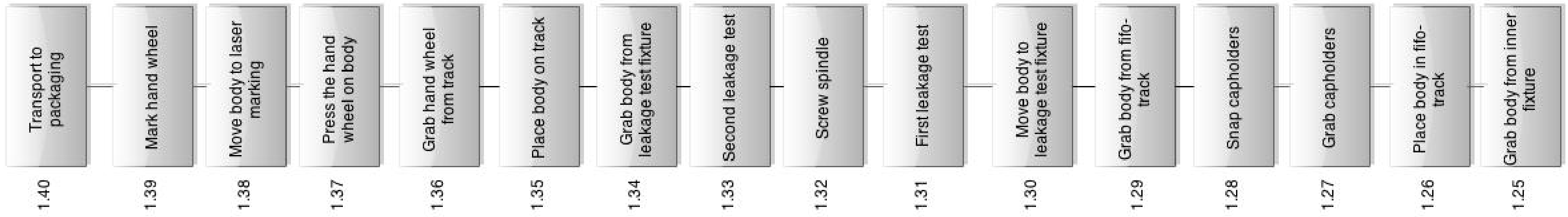
LoA Mech	Task number	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.22	1.23	1.24
7																									
6		B	B	B	B				B	B		B		B		B	B	B			B		B		
5						B	B	B			B		B		B				B	B		B		B	B
4																									
3																									
2																									
1																									

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	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20	1.21	1.18	1.19	1.20
7																									
6		B		B			B		B		B		B					B		B	B	B	B	B	
5			B		B	B		B		B		B		B	B	B	B		B						B
4																									
3																									
2																									
1																									

Rotary table operations



Non-rotary table operations



LoA Table: Non-rotary table operations

LoA Mech	Task number	1.25	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.38	1.39	1.40
7																	
6		B	B		B	B	B				B	B	B	B		B	
5				B				B	B	B					B		B
4																	
3																	
2																	
1																	

LoA Info	Task number	1.25	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.38	1.39	1.40
7																	
6				B	B			B	B	B			B	B			
5		B	B			B	B				B	B			B	B	B
4																	
3																	
2																	
1																	