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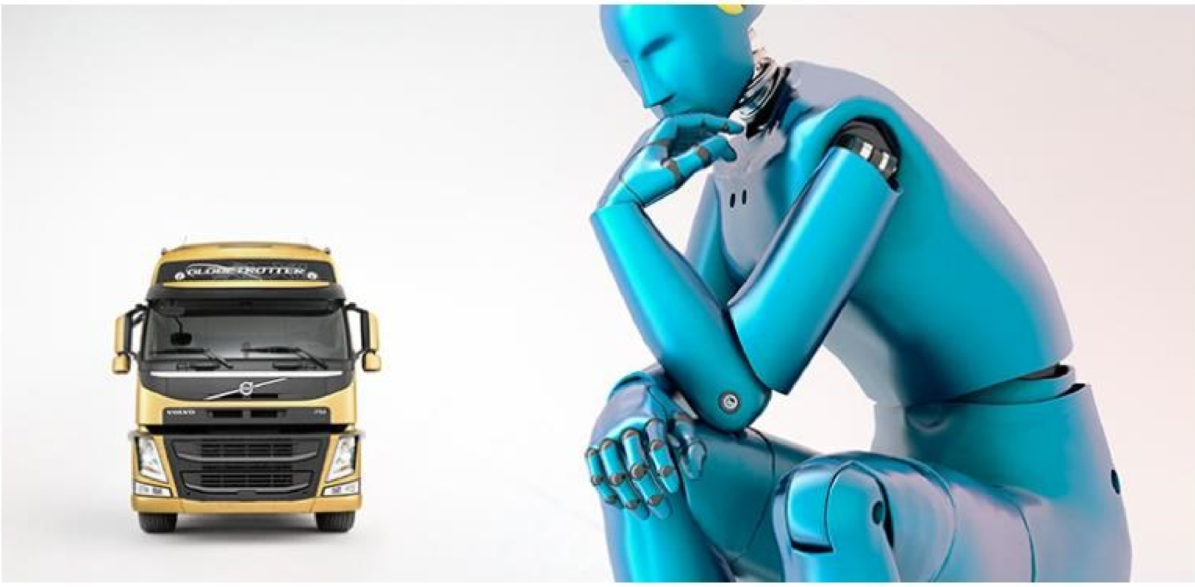

Operator - Robot collaboration

Creation and evaluation of a collaborative Operator – Robot workstation

Thesis work within Mechanical Engineering

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Creation of supporting documents

A method for surveying knowledge within a Product Development Process.

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Abstract

This thesis work was executed at AB Volvo Trucks at the department of Manufacturing Technology in the Chassis and Final assembly process. The vision of the company is to provide heavy duty trucks with reliability all over the world, based on their core values – quality, safety and care.

The main task of this project was to investigate, explore and evaluate the collaborative human-robot relationship and interaction, with the purpose to increase the level of automation in the final assembly of heavy duty trucks. The project consisted of an acclimatization period, robot programming, layout design and a psychosocial evaluation regarding the aspects of working together with a robot.

By implementing this kind of automation, it is possible to eliminate none ergonomically tasks for the operator and at the same time increase the quality - a win-win situation. The arousal measurements showed that it is important to keep the operators involved in the process and to let them know why the change is needed. By doing this everyone will be given a chance to feel more involved and that will ease the change in the process and minimize the amount of fear for this kind of collaborative robots.

Acknowledgements

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Table of Content

1. Introduction

The introduction is provides to the reader all the background information of this thesis, this including purpose, delimitations and research questions.

1.1 Project Background

Most manufacturing companies have a low level of automation in their final assembly processes, often due to a high level of product variation. A robot is more efficient when it comes to repetitive work compared to a human, while humans are more flexible and better at improvising, whereas they can handle large variations better [1]. As a result there are very few robots in final assembly processes. By a future implementation of more advanced and flexible automation techniques called collaborative robots, the final assembly processes can be more qualitative and with better ergonomic, but still be flexible. This will save both time and money due to a decrease in injuries at work and less time spent on fixing quality issues.

Today when looking at Volvo Trucks they offer a lot of different truck models which leads to a very high degree of variation in their final assembly [2]. This is a problem when to implement a higher level of automation due to the difficulty of programming a robot that can be flexible enough to handle varying assembly procedures.

1.1.1 AB Volvo and Volvo Group Trucks Operations

AB Volvo was founded in the year of 1927 in Gothenburg, Sweden as an affiliate in SKF with the purpose to produce cars. The manufacturing of cars was later sold to the American company Ford Motor Company in the year of 1999, who then in 2010 sold it to the Chinese car producer Geely.

The first truck was produced in 1928 and today AB Volvo also includes the manufacturing of buses, construction equipment and marine and industrial drive systems.

Volvo Group Trucks Operation is the part of the company responsible for the manufacturing of trucks, which today also includes Renault Trucks, Mack Trucks and as a part-owner of the Chinese Dongfeng Commercial Vehicles. Volvo Group Trucks is one of the world leading companies in the manufacturing of trucks and has factories all over the world [3].

1.1.2 The fuse box assembling procedure

Today the fuse box is pre-assembled with metal plate and fuses from a supplier. The fuse box, which is delivered in a pallet, is then placed on a rear plate which also works as a fixture. The fuse boxes come in three different variants and varies by the number of fuses. The focus of this project is on the assembly process of the two most common (part number 21717590 and 21717591).

In the fuse box, power cables of different sizes and with different color code (to determine the location of each cable) are placed on each fuse and secured by a nut. These are then fixed by cable ties through tracks in the rear plate. Power cables as well as the fuse box are then secured with an electric wrench to guarantee the right torque. Before using the wrench, the operator must scan related documents and choose the right sleeve (3 different) and in the right order. If not used correctly and in the right sequence the wrench does not work. When the fuse box is assembled at the rear plate with all its belonging cables, the whole package is placed at a trolley which is later moved to the production line.

1.2 Purpose

The aim of this thesis is to investigate, explore and evaluate the collaborative human-robot relationship and interaction in final the assembly process. This as a first step in the process to increase the level of automation in the production of heavy duty trucks. The goal is to create a collaborative workstation at Volvo Group Trucks Operation for the assembling of a fuse box and answers a number of questions formulated below.

1.3 Research questions

Collaborative workstations are still relatively uncommon, but it may become a very effective approach in the future. If humans and robots specialize to perform their specific tasks that will suit them the best, for example letting the robot do the repetitive work and the human do the improvising, the efficiency will increase.

Since both the technology and the mindset (when it comes to the interaction between human and robot) is relatively new, there are a lot of aspects to take into consideration when designing a collaborative workstation. New questions will arise that must be answered before it is safe to implement it in a working environment.

This thesis will focus on the following issues:

- What type of tasks are suitable for the human and what type of tasks should be done by the machine?

- Which is best way to integrate the operator in a collaborative environment, both physically and mentally considering different types of fears and injuries?

- Which type of factors are important to consider regarding safety, ergonomics and efficiency for implementation of a collaborative workplace?

- Evaluate the possibilities for a collaborative workstation in the assembling of a fuse box.

1.4 Delimitations

When evaluating the possibilities for a future implementation of a collaborative workstation, there are a lot of different aspects to consider. Due to time limitations, the project will not focus on the factors listed below.

- Assembly instructions for the operator.
- The economic aspects of any gains and expenses for the project.
- The project chose to evaluate and work with the two most common variants of the fuse box (part number 21717590 and 21717591) and neglecting the other more rare variants.
- Evaluate the possibilities for CE-marking of work station.
- Create a complete workstation to implement in Volvos manufacturing process.
- Only evaluating the possibilities for this workstation working with the collaborative robot from KUKA. We are therefore not evaluating any other models of robots, collaborative or non-collaborative.

2. Frame of references

This chapter is partly a benchmarking process in order to provide relevant background information regarding the subject automation and specifically collaborative automation.

2.1 The term automation

The word "automation" could be described as the technology of a machine agent (usually a computer) for execution of a function that was previously carried out by a human [4]. Automation can be both physical (mechanical) and cognitive (information and control) and in different level of advancement. Physical automation is the amount of human muscle power used to complete the task and in what extent mechanical devices and robots are used. Cognitive automation instead refers to how much information and support the human operator gets doing its work and what level of control he has [5].

The techniques regarding both physical and cognitive has developed a lot since the beginning of 2010. This is due to the technical revolution and the increased competition between different companies and hence higher demands on efficiency in the production processes. Better efficiency as well as higher level of quality, flexibility (resources, volume, route and variants), time savings and ergonomic benefits is the essential reason to why companies choose to automate [6].

2.2 Collaborative automation

Collaborative automation means that an operator works together, on the same object and at the same time and space as a robot. This is an area that is upcoming and there is and has been a lot of research effort focusing on the abilities of human-robot collaborative work cells.

The drive is the demands for higher quality, efficiency, flexibility and productivity in an industrial production line, as well as the reduction of human stress and workload [7].

The robots that are used in collaborative automation is much smaller and has a much higher level of safety than the traditional ones seen locked in behind a safety fences in the manufacturing industry. These traditional robots are often much heavier and therefore they can cause greater damage due to their size, but also because they lack several safety functions like the collision stop. The collaborative robots are lightweight and has a number of different safety functions, making it possible for it not be behind a fence. An example of a safety function that is crucial is the collision stop. This function stops the robot immediately when it encounters any kind of object, allowing the operator to safely interact with the robot without being injured.

There are a lot of other important aspects to consider when integrating a robot in a working environment. Research has shown that trust, workload and risk is the major human factors affecting the use of automation technologies [8]. When implementing a higher level of automation, it is also crucial not to forget the wellbeing of the operator, both physically and mentally. Just because the workload for the operator is reduced it does not mean that the comfortable level increases. A factor like boredom might lead to tiredness and the operator might not be as alert as the situation demands if there is to be an emergency. The solution is HCA - Human Centered Automation. An idea focusing on how to reduce the workload of an operator in a way that will not compromise with its focus and wellbeing.

2.2.1 Safety regarding human-robot collaboration

To be able to ensure the safety for the operator in a collaborative environment there are national and international standards and laws monitoring these types of operations. These standards and laws are based on three main strategies:

- Adaptive safety (avoid collision without stopping the operation)
- Crash safety (only safe collisions with limitations in the power of the robot)
- Active safety (timely detect collisions)

Many of the directives includes safety measures regarding robot design and electrical equipment, and mainly it consists of the following instructions:

- It is necessary for every robot to be equipped with an emergency stop as well as a protective internal stop.
- The speed of the robot needs to be controllable. The velocity in a collaborative environment is not allowed to exceed 250 mm/s.
- Robots should be provided with sensors to be able to do safety rated monitored stop.
- Power and force limitations should be able to be programmed.
- Limit the robot's motion. Either by invisible fence (programmed walls) or external protection.
- Minimum separation distance considering hazards regarding the workspace layout, the tool or dangerous items held by the tool.
- Avoiding potential collisions by letting the robot slow down or reverse course along its path.
- The workspace where the operator can collide with the robot should be designed in such a way that would reduce the risk accidents. Minimize rough surfaces in the collaborative area and let there be space for the operator to move around without getting trapped.
- The tool and the robot must have corners with a minimum radius of 10mm [9].

2.2.2 HCA - Human Centered Automation

Human centered automation is about maintaining the operator as the final authority over the automation, and not the other way around. It is therefore important, when implementing more advanced automation to an organization, to inform everyone who is involved in the process about the transformation and the aims of it. It is also of importance that there is a good understanding of the human behavior related to cognitive, psychology and sociology engineering for it to be successful [10].

The intention is to put the operator in charge and allow him to do the decision making. This while giving him computer-based advice about everything he needs to know. You allocate to the robot the most advantageous task best suited to the robot, and allocate to the human the tasks best suited to him [11].

2.4 Dynamo ++ - Dynamic automations strategies

The Dynamo++ method has been evaluated since the beginning of the 20th century and is a result of a number of Swedish science projects. Dynamo++ is a method used to improve already existing assembly processes by, in a structured way, mapping a production section and suggesting possible automation solutions. [12]. Included in the Dynamo++ method is the HTA-analysis, DFAA-analysis and the LoA. These are described below.

2.4.1 HTA - Hierarchical Task Analysis

Hierarchical Task Analysis is a method that was used to organize the assembly assignments for a workstation in order to provide a clear overview. The HTA-analysis is then used as a support when evaluating a work station using for an example DFAA or LoA described below.

When doing a HTA-analysis you go through the assembly process very carefully and structure it in a tree structure with the main element broken down into stages and subtasks. It is an important step if the intention is to increase the amount of automation at the workstation, as the HTA-analysis gives a clear view over what is suitable to automate and what is not [13].

2.4.1 DFAA - Design for Automatic Assembly

Design For Automatic Assembly is a method which helps people that are working with product development to make their product as mounting friendly as possible from the beginning (when it comes to automatic assembling). The DFAA-analysis was used as a valuation method to point out the weaknesses of a product and how to improve them.

The idea is to provide a guide or a help for the constructions engineers based on both a qualitative- and quantitative assessment, weighing how well the product is adapted for the mounting of its components as well as what performance that can be achieved.

The assessment is done on a product level more general and at a component level which analyses it more in detail. You look at the different components and evaluate how well they meet the construction requirements and by answering several questions. The questions have three alternative answers giving it a certain point (1, 3 or 9), where 9p represents the best solution from an assembling perspective. 3p represents an acceptable solution while 1p is an undesirable solution.

After the analysis you evaluate the result by calculating an index. A product with only 9p gets an index at 100%, and depending on how close you get to 100% it gives an indication on how well adapted the product is for assembling it automatically. An index at 70% or above is desirable for implementation of a robot cell [14].

2.4.1 Level of Automation

This is a method that was used to evaluate the amount of automation that is used today at the workstation. The assembly procedure was carefully analyzed and then specified in accordance with a chart which automation level each stage comprises. When using LoA you evaluate the workstation from a physical perspective as well as a cognitive perspective. The physical evaluation answers questions regarding how and to what extent the operator uses tools or machines in his work. The cognitive evaluation focuses on how much the operator must think for himself to complete the task and to what extent a system is guiding him through it (e.g. vision systems).

LoA presents 49 possible combinations and levels of automation and provides a good overview over how automated the station is and where there are room for improvement [15].

2.5 Task allocation

There are a lot of aspects to take into consideration before deciding on who should do what. First and foremost, it is important to distribute the tasks so that you achieve maximum utilization in the assembly process, both when it comes to efficiency and safety. To reach this goal it is important to have a close linkage between the automated system and the operator. Human and robot has different advantages regarding the assembly process and the challenge today is to combine theses different attributes to create an “all-star team”.

<u>Advantages for the human:</u>

Detection - Ability to detect important signals through sight and hearing

Judgment - Ability to act by using experience and logic.

Improvisation - If something unexpected would happen then the human can deviate from the standard procedure and improvise a solution.

Storing information (long term memory) - Ability to store information and recall it when needed. For example, improvising solution during an unexpected turn of events.

Reasoning inductively - See patterns and therefore can anticipate events.

Perceive patterns - Reflect and act on light and sound

<u>Advantages for the robot:</u>

Speed - High velocity (mm/s) and quick respond to signals.

Power - Applying force precisely and smoothly will improve the quality.

Store information briefly - The information will be erased if not needed.

Simultaneous operations - Doing multiple tasks at the same time

Repetitive work - Perform repetitive tasks

Reasoning deductively - The rules are logical and followed [16].

2.6 Safety requirements

When designing a collaborative workstation the safety must be the greatest priority. Although the robot is programmed to work in specific and detailed sequences, there is still a risk for the operator to get injured if he or she makes a mistake and collides with the robot. These mistakes can be unintentional due to forgetfulness, rule-based errors or a faux pas but the damages could be devastating. It is therefore important to anticipate the mistakes that could occur and from the beginning do what is necessary to prevent them.

2.7 Psychosocial evaluation regarding human-robot collaboration

Interview

There are three types of interviews:
- structured interview
- unstructured interview
- semi-structured interview

Unstructured interview was used in this project to gather important information based on the operator's feelings and experience. The questions are based on the operator's response in the situation with just a few formulated questions in advance. This is a great way to gather useful data but there is one disadvantage with this type of interview because it lacks reliability and precision due to each interviewee is asked different questions. [17]

Arousal

An arousal-clock was used to monitor data such as sweating and hear rate from the operator when testing the workstation. The device straps around the operator's wrist when working to analyze the potential arousal in a specific situation. [18] The result will appear in curves and makes it easy to point out changes, for example increasing heart rate. This increase in heart rate can depend on that the operator experience excitement or fear which can be tracked down to a specific part of the work sequence. It is important to analyze this part and evaluate it compared to the result.

3. Method

This chapter describes the methods that were used throughout the project.

3.1 Method Selection

The research procedure was done as an inductive study. Information was gathered, analyzed and conclusions were made based on qualitative observations and experiences.

The methods that has been used in this thesis are listed below:

- DYNAMO++ (including HTA, DFAA and LoA)
- Quality analysis
- Safety analysis
- Arousal measurement
- Interviews and observations

3.2 Status analysis

A lot of hours were assigned to investigate the chosen workstation before the development of a future workstation could begin. This was made by filming the entire work process and document each and every step according to the Dynamo++ method. First in an HTA-analysis, where the result was evaluated and then further investigated in a DFAA-analysis to define the possibility to achieve a greater level of automation.

3.2.1 Quality analysis

After discussing with the team leader in charge, the current quality issues for the workstation were pointed out. This information was used to further investigate the foundation of the quality issues and what kind of measure that has to be done to solve the problem. This knowledge was important when distributing the tasks for the operator and the robot respectively.

3.2.2 Task allocation

When deciding what tasks that were suitable for the robot and the human respectively for the assembling of the fuse box, a task allocation was performed based on articles written on the subject. The robot picked and placed the fuses due to its ability to handle repetitive work whereas the operator handled the cabling.

3.3 Safety requirements

A risk assessment must be carried through before implementing a robot in any environment, including a testing area like Pilot Plant. A safety analysis (ASA-analysis) was performed to illuminate what kind of risks to take into consideration when installing and programming the robot (see result). Later on the production leader at Pilot Plant in co-operation with their production engineer and the one responsible for the safety did a more thoroughly risk-assessment. Each operation was analyzed, assessed and the potential hazards where then supplemented with the necessary measurements needed.

The hazard identification process shall take into consideration several factors according to current standards (ISO/TS 15066:2016) for a collaborative workspace. ISO 14121-1_2012 provides practical guidance and examples of methods for the evaluation of the safety of machinery.

An important part in the design process of a collaborative workstation and the associated cell layout is to eliminate hazards and reduce the risks. A collaborative workstation shall meet the special requirements regarding safety according to a number of ISO-standards listed below.

Based on these standards, the workstation was designed and evaluated and is presented below *Result.*

ISO 10218-1:2011 and ISO 10218-2:2011
ISO TS 15066:2016
ISO 12100:2010

ISO 13849-1: 2015 and ISO 13849-2:2015

3.4 Layout and Design

When designing the layout for the collaborative workstation there were a lot of aspects to consider. First step was to divide the available workspace into the areas necessary, such as an area for the material feed, an area for the fixture of the fuse box and an area for the operator to work at without encountering the robot.

A palette for the material (the fuses and the metal plate) and the tool base was drawn in Catia and 3D-printed. The fixture for the fuse box as well as the cabling was also drawn, printed and then fixed to the table.

3.5 Robot programming

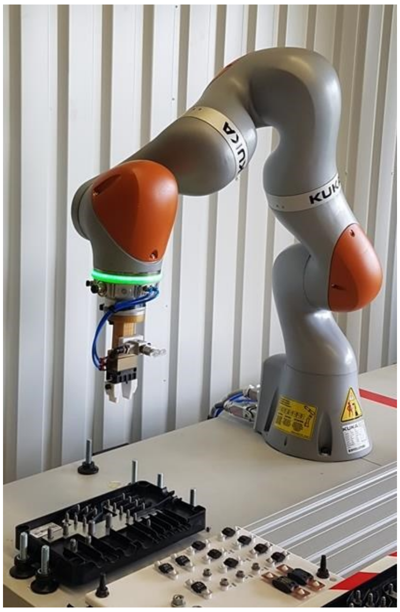

Figure 1: Collaborative robot, KUKA LBR iiwa.

To be able to program the robot it is necessary to have a good insight in the KUKA controller system. KUKA held a two-day course introducing the software used to program the robot, called SunriseWorkbench. The language used is Java and therefore knowledge in Java programming is needed. When all the fixtures were placed and fixed and the tool was attached and connected with the pneumatic, the robot was ready to be programmed. First of all, to be able to open and close the gripper it had to be installed to the robot via an EtherCat plug-in module (Ethernet for Control Automation Technology) and then connected to the software via a control system called WorkVisual. Once it was installed the gripper could be opened and closed using the SmartPAD, the controller with which you move the robot. A suction cup was also added to the tool and installed in the same exact way.

By adding coordinates to different positions the work sequence could be programmed via the workbench called Sunrise Workbench or by teaching the robot these coordinates and code the work sequence. An example of a program sequence can be seen in appendices 5.

3.6 Psychosocial evaluation regarding human-robot collaboration

To investigate how the operators at Volvo Trucks Tuve felt about robots in general a survey (see appendices 4) was made with the intention to clarify possible prejudices. The survey was sent out via Google Forms to operators working in the factory to gather information regarding the psychosocial factors related to working with a collaborative robot. The survey starts with a video showing an operator working together with a robot and then continues with questions regarding automation in general but also how they would feel working together with a robot as seen in the video.

To further evaluate how an operator felt when working together with a robot a test simulation was set up with different assembly procedures to analyze potential stress factors. During the test simulation, the operator wore a wristlet measuring sweating as a part of an arousal measurement. The wristlet was then connected to a computer where the result was analyzed through a curve in a diagram. A rise of the curve could show an increased level of stress, but sweating could also be a result of excitement. Therefore the measurement was combined with an interview to fully determine how the operator felt.

4. Results

In this chapter you will find the results of the methods used and what was presented to Volvo, in order to provide them with the necessary information for them to use in future implementations of collaborative workstations.

4.1. HTA-analysis

The HTA-analysis was made to analyze the depth and width of the workstation that is how many tasks the procedure includes (width) and the number of sub-tasks they consist of respectively (depth). This was later used in the LoA-analysis to evaluate the level of automation. See appendices 1.

4.2 DFAA – analysis

The DFAA-analysis resulted in 68 % which is a great percentage. It shows that there are good possibilities to implement advanced automation at the workstation. For complete DFAA-analysis, see appendices 2.

The reason why this workstation got such a high percentage is because the tasks and the details that are involved in the process are easy to handle. Therefore the potential to automatize some parts of the process increases. For example, the fuses and the nuts are easy to pick up and assemble. There are few unique details to consider and it is easy to fix and attach all base object without losing the orientation. Most of the details are easy to grip, hard to break and they do not weigh much. The power cables and the tie straps on the other hand are more complicated to handle and therefor difficult for the robot to assemble.

4.3 Level of automation (LoA)

Two LoA-analysis were made (see appendices 3), one for the current state and one for the future state. When analyzing the result for the current workstation it is obvious that the automation level is very low. There are no checklists or manuals to follow and the operator learns the correct procedure by decision giving. Most of the work is also done manually except for tightening of the nuts and the clamps. The nuts are tightened with an automated screwdriver and the clamps are tightened with a flexible hand tool. The result indicates that there is potential for achieving a higher level of automation for this work station.

While comparing these results with the DFAA-analysis (which gave an index at 68%), it is clear that the opportunities are good when it comes to the possibility of increasing the automation level and that the workstation is suitable for a collaborative robot.

4.4 Quality analysis

The quality issues regarding the selected workstation are very few. However, the most common problem is that the operator picks the wrong fuse box, which happens about ten times a year. This happens because the two most common variants only differ in the amount of safety fuses mounted by the supplier. The assembly instructions specified in a system called SPRINT tells the operator what type of fuse box to use. After speaking with the team leader in charge the problem occurs because the part numbers are too similar. The two only differs in the last number, which makes it easy to pick the wrong one. After visiting the workstation it was also noticeable that the two variants was stored to close to each other and with their labels partly hidden, additional two factors contributing to the quality issue.

The operators are not able to detect if they have picked the wrong fuse box, and is first noticed further down the line when they assemble the batteries and are missing one safety fuse. This leads to a lot of extra work. First the fuse box must be disassembled together with all its belonging cables that was assembled at the pre-assembling workstation. You then must switch to the correct one and then put it back along with all cables. When tightening the nut again, it is difficult to ensure that it is tightened with the right torque without the correct machine, which leads to another future quality issue.

The result of the quality analysis is a solution which implies the robot to build each fuse box sequentially, one at the time according to the system that controls the sequence order of the trucks to be produced. This eliminates the quality issue mentioned above, giving the operator only one ready fuse box to choose from. When the operator has taken a fuse box, a sensor activates telling the robot to build the next one in line. Due to the delimitations of this thesis, this is only a suggested solution for future implementations and how to eliminate similar problems.

4.5 Collaborative workstation

The result of the evaluation of a collaborative workstation, which also is the foundation of the decisions made regarding the design and task allocation between human and robot.

4.5.1 Task allocation

The task allocation between the operator and the robot was decided based on the respective advantages (mentioned in chapter 2.5) of human and robots. The assembly tasks where distributed as follows:

Task for the human:

- Pick up the fuse box, placing it on the rear plate
- Attach the clips
- Attach the cables
- Attach the cable ties and tightening
- Enter the nuts and tightening
- Scanning CC-document Task for the robot:
- Assembling of the fuse box:
- Pick up and place the metal plate
- Pick up and place the fuses
- Providing nuts for the operator

4.5.2 Safety requirements

The result of the ASA analysis is seen below.

Task assignment	**Risk/Hazard**	**Recommendation**
Start the robot	- Collision - Crush hazard	- Dead man's switch - Safe distance
Turn of robot	- Collision - Crush hazard	- Emergency stop - Be able to turn of robot from a safe distance
Positioning of the robot	- Collision with operator/other personnel - Collision with other equipment	- Positioning the robot in a way that will minimize the risks for collision
Collaborative area	- Collision - Crush hazard	- Physical protection (protective covers) - Clear marking of the collaborative area - Lower speed - Use the robots programmable safety functions
Unauthorized personnel in the work area	- Collision - Crush hazard	- Clear marking of the work area - Use the robots programmable safety functions
Changing of the tool	- Collision - Crush hazard	- Turn of the robot

Figure 2: ASA-Analysis.

4.5.3 Layout and Design

The result of the layout and design evaluation is presented below.

4.5.3.1 Layout

The layout is divided into three areas (see figure 3), one collaborative area, one where only the robot is allowed to move and one for the operator to work. In the working area the robot is allowed to move at a speed of 750 mm/s comparing to the collaborative area where it is only allowed to work in 250 mm/s. The robot was placed in the back center of the table

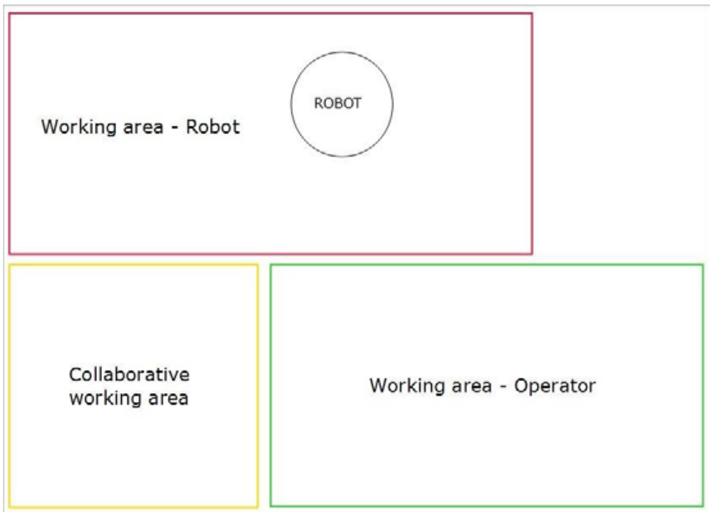

Figure 3: Workstation layout.

4.5.3.2 Tool base

The first tool base was designed with a 45-degree angle from the center axis and a 90-degree angle between the two tools (gripper and suction cup), see figure 4. The problem that occurred because of the 45-degree angle from the center axis was that it forced the robot to move in an ineffective way, not able to use its last rotating axis. Therefore a new tool base was created (see figure 5) with the gripper in line with the center axis. This allowed the robot to move more effective and made it easier to program the assembly procedure.

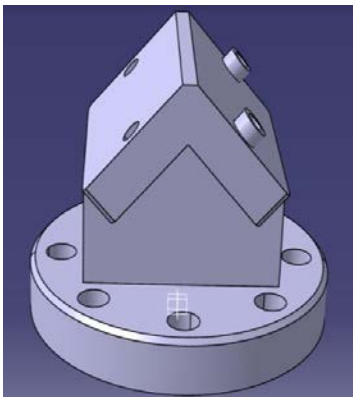

Figure 4: First draft

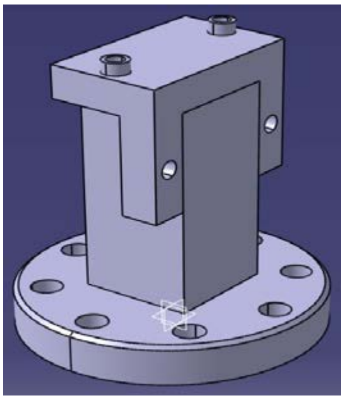

Figure 5: Second draft

4.5.3.3 Material palette

The tolerances are tight when to place the fuses in the fuse box. To ensure that the fuses always lie in the same position they are placed on a conical elevation. This allows the robot to pick them in the exact same way and therefore guarantees that when placing the fuses in the fuse box they will always fit.

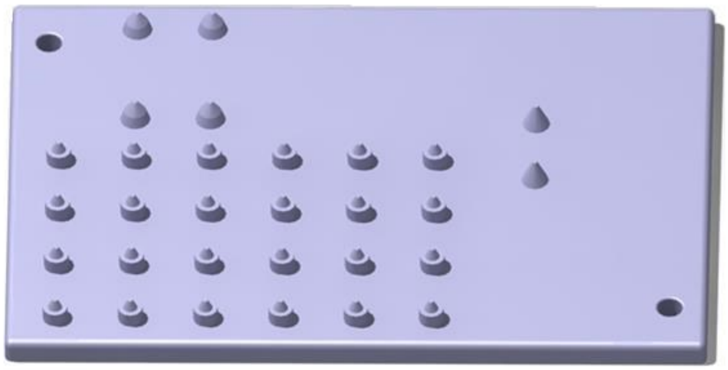

Figure 6: Material palette.

4.5.4 Robot programming

There are two different types of fuse boxes available and the operator can choose which fuse box to assemble by choosing it on the SmartPAD. Once the alternative is chosen the robot start the assembly procedure.

To evaluate the collaborative environment the operator was given tasks to accomplish nearby and in co-operation with the robot. In the beginning of the work sequence the robot picks up a nut and delivers it to the operator, this after it has placed two fuses. When the operator pushes a button the robot lets go of the nut and the operator attaches it to the stud. During the time that the nut is entered by the operator the robot gets the second nut and this time the operator has two seconds before the robot will drop the nut automatically. The robot will then continue assembling the fuses and by the time it has assembled three of the lower fuses (showed in figure 7) it will wait for 10 seconds to let the operator enter three nuts (which the operator picks himself) to secure the fuses.

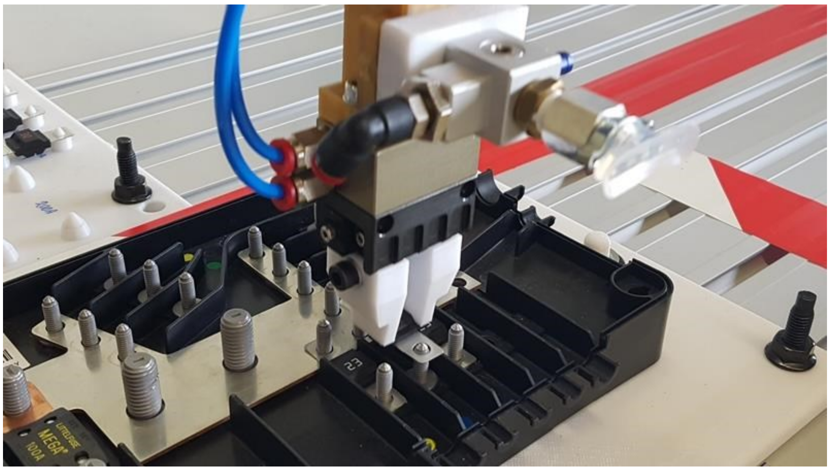

Figure 7: Robot placing fuse in fuse box.

After 10 seconds the robot will continue assembling the remaining seven fuses. During this time the operator will place three cables tugs on the fuses that where secured earlier. Then the operator secures the cables with three nuts and tie straps.

When the robot is done placing the remaining fuses it will provide the operator with four nuts, one at the time, and wait at a given position in two seconds before releasing the nut automatically. The operator will place their hand under the robot when the red light turns on. The operator takes the nut and enters it on a stud according to instructions.

4.5.4.1 Safety configurations

Once the robot was installed several safety configurations had to be programmed to make the robot safe enough to work with. The safety functions applied is listed below:

- Protective virtual walls:
  Virtual walls programmed around the working area of the operator so that the robot stops if it departs from its route.

- Velocity monitoring:
  A function monitoring the velocity of the robot and stops it if it would exceed this limit. It is set to 250mm/s in the collaborative area and 750mm/s in the robot area according to current ISO-standard.

- Collision stop:
  A function unique and necessary for it to be a collaborative robot and stops the robot if it were to come in contact with the operator or another object. The limit is programmed to a suitable torque level, in our case set to 10Nm. If the robot should "feel" a torque greater than 10Nm it will stop.

- Lightning in the flange:
  A distinct light around the flange of the robot allows the operator to on a distance determine if the robot is working or not. Set to green when working and red when not working.

4.6 Psychosocial evaluation regarding human-robot collaboration

The result of the psychosocial evaluation is presented below.

4.6.1 Arousal-measurement

The evaluation of the heart rate (bpm) and the conductance of the skin (EDA) were analyzed by comparing the different curves with the cycle time of the workstation. The result showed a clear pattern in the rise of the heart rate and conductance, when the operators were working close to the robot. A rise of the curves also occurred when the operators felt that they were under pressure when they had to accomplish a task during a certain time.

By comparing the curves it was noticeable that the heart rate differed in some way depending on which operator that did the test. The heart rate was constantly high for some of the operators and for others it was easier to point out when the peaks occurred.

The curve below is from an operator with low experience in the assembly process but who is used to see and integrate with the robot.

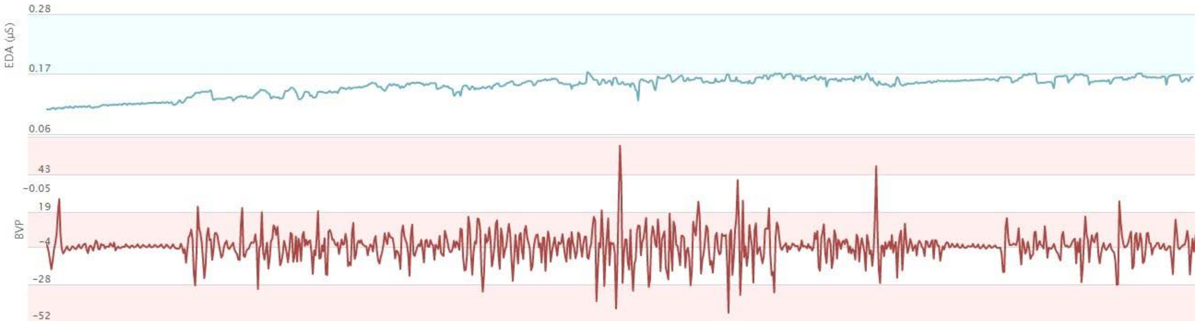

Figure 8: Heart rate and conductance, curve 1.

This curve (curve 2) is from an operator with great experience in the assembly process and who is used to see and integrate with the robot.

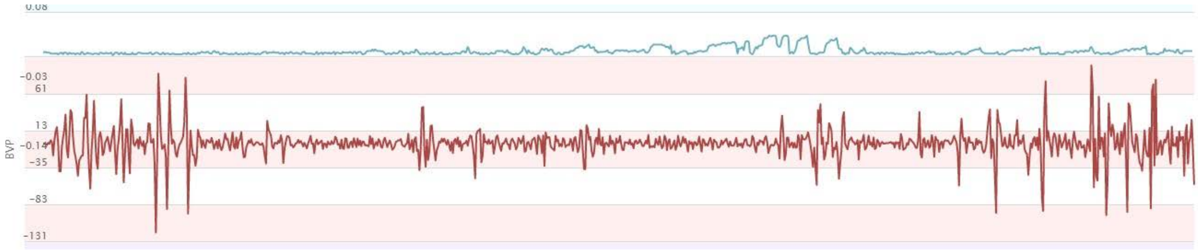

Figure 9: Heart rate and conductance, curve 2.

This curve (curve 3) is from an operator with great experience in the assembly process but who is not used to work with the robot in any way.

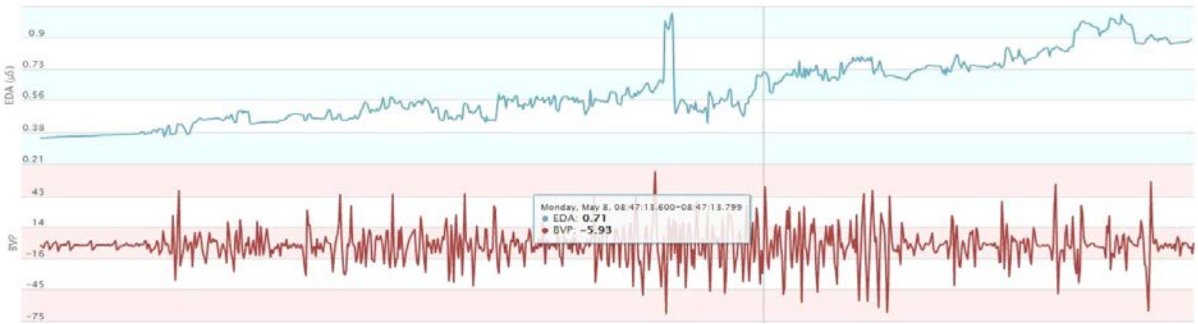

Figure 10: Heart rate and conductance, curve 3.

4.6.2 The survey

The result of the survey is based on 27 answers from people in the automotive industry from the ages of 20 to 55. People's opinions regarding automation are very much divided. 38.5%

believe that automation will ease their workload and the other 38.5% believe that the robots eventually will replace them.

After watching the video where an operator working together with a robot, people responded differently. 38.5% believed it would feel ok working with the robot and 38.5% of them would feel discomfort or fear. For full questionnaire, see appendices 4.

5. Discussion

In this chapter the results of this project are discussed within the frame of references and the methods used.

As mentioned before, the only major quality problem related to the work station is that they pick the wrong fuse box. To solve this problem, the thought is to let the robot do the decision making by connecting it to the system that controls the order in which the trucks are built. The robot builds the next one in line giving the operator only one fuse box to choose from. When the operator then takes a fuse box, a sensor activates telling the robot to build the next one in line. Due to this project only being a pilot project, this was something that where never implemented, but what we suggested as a possible solution to the quality issue.

When we were deciding on the task assignment we had to take into considerations both the advantages for the operator as well as the robot. Tasks like attaching the cables and the clips is too complex for the robot to handle, this because its low ability to handle work variation. Instead we distributed these assignments to the operator since the he or she can reason inductively and base the decisions on both judgment and improvisation. The advantages for the robot is that it can work fast, smoothly and precisely. Especially if the tasks involve repetitive sequences were the rules are less complicated and more logical. That is why we let the robot assemble the fuses and pick up and deliver the nuts to the operator.

One of our main goals with this project was to analyze the psychosocial aspects of a collaborative working environment. Due to this, halfway through the project we decided not to set up the whole station as it looks now, but to focus on sequences that evaluates how it feels for an operator to work with a robot. This is because we together with our mentor felt it was not necessary for the project to set up the whole station and partly because we could not get the robot as safe as it had to be for it to work with an operator not previously involved in the project. This mainly regarding the tool that was only for testing, which made it hard for us to make collaborative with all radii larger than 10mm. Therefore the process was set up as mentioned in the result and with this procedure in combination with the arousal measurement and a quick interview, we got a good understanding of how the operator felt.

By evaluating and comparing the curves from the measurement we noticed that there were some similarities and some differences depending on their previous experiences with the robot. Something that most of the operators had in common was that their hear rate peaked at the same time in the work sequence. The first peak was in the beginning when the robot provided the nuts. The second peak appeared in the end of the sequence when the operator attaches the cables at the same time as the robot assembles the last fuses. These two situations appear to increase the stress level of the operators. The heart rate peaks can also be due to fear of operating near the robot but also due to stress because of the time pressure.

The curves looked different depending on what kind of experience the operator had. Curve (1) is from an operator with no assembly skills but with experience of integrating with the robot. The heart rate peaks in the beginning of the process and when to assemble the cables, the stress is probably increasing due to low experience. But when analyzing the rest of the sequence it is noticeable that the heart rate is constant and low the rest of the time. This is probably because the operator has got more used to the robot and its moving pattern.

Curve (2) is from an operator with experience in assembling and with experience of integrate with the robot. The curve shows a heart rate that is even throughout the process, which could be a result of the operator being used to the environment.

Curve (3) is from an operator with experience in assembling but who has never seen the robot. This curve has its peaks, but the heart rate is high throughout the process. This can be a result of the operator being nervous in general. It is important to have in mind that the heart rate can depend on a lot of other factors as well. Factors like gender, age, physics and performance anxiety must be taken into consideration and therefor the result is not scientifically proved, but more as a guideline.

Another interesting thing is that the conductance is increasing more rapidly (curve 3) for that operator. This is a sign that the operator is active and alert and that can depend on the great experience in assembling. When analyzing all the curves from all the tests we have done you can see that there is a pattern in these results that support this conclusion.

Another issue to evaluate was the waiting time. Who should wait on whom and how did the operators feel when they had to wait for the robot to release the nut? Doing the quick interview afterwards and with some telling us right away, it was clear that a sense of stress occurred when they had to wait on the robot. And therefore the solution may be for the operator to press a button when he is done, telling the robot to proceed with his task. This will probably make the procedure less stressful for the operator. At the same time, designing the process so that the operator has to wait on the robot, makes it possible to control how the operator works. If the operator cannot perform its next task before the robot is done whit his, you are able to control the cycle time and prevent that the operator works faster than he should. Even though the operator may feel a bit of stress in the beginning when being dependent on the robots assembly procedure, it may in the end, when he has got used to it, make him less stressful as he knows he cannot expedite the process. A problem when letting the operator wait on the robot is that the operator may try to deviate from the assembly procedure to speed up the process. This could be a safety issue due to the increased risk of a collision between the operator and the robot. This must somehow be prevented.

When reviewing the survey, it is clear that the general knowledge about automation and what it means is relatively low, especially when it comes to collaborative automation. Almost 40% of the respondents thought that a when a company want to implement a robot, it is only done to replace the workers with machines in for them to save money. The other 40% actually thought that the robot was there to help them and to ease their work ergonomically, which was a surprisingly good percentage. But because of the factor that almost half of the respondents thought that the robot will replace them, it is of importance that the operators gets involved in an early stage, showing them that the robot is not there to replace them, but to ease their work.

6. Conclusion and recommendations

This chapter summarizes the thesis and answers the questions formulated in the beginning of this project, with suggestions for future implementations of a collaborative workstation are presented.

6.1 Questions answered?

In the beginning of this report there were five questions formulated and which this project was set up to answer.

> *What type of tasks are suitable for the human and what type of tasks should be done by the machine?*

As mentioned before, the robot and the operator have different advantages when it comes to their abilities in the assembly process. These abilities have been considered when distributing the tasks to achieve an optimal task allocation.
The tasks that are involved in this workstation makes it an optimal station to evaluate the human- robot collaboration considering the mix of advanced and basic tasks that appeals to both the operator and the robot. These types of tasks, combined with the layout, also give us an opportunity to explore the close cooperation between man and machine. By analyzing this close co-operation it will help us to understand the relationship between the operator and the robot and how to improve it.

> *Which is best way to integrate the operator in a collaborative environment, both physically and mentally considering different types of fears and injuries?*

The survey that was distributed, along with the tests made in the end clearly demonstrated that it is important for the operator to get used to the robot in an early stage to reduce any forms of fear. One way to do this initially, as this is a very early stage with this kind of robots in the factory, is to place a moving robot in an area where there is a lot of people passing through. This allows the personnel to come close to it, feel it and see it in a harmless environment. Maybe let it serve candies for the personnel? When an operator later shall work together with the robot, the operator knows what to expect and thereby the first obstacle of fear is passed. Another way to further integrate an operator to this new kind of collaborative working environment is to have a one-day course, letting the operator do some basic programming of the robot including programming of the safety functions. This allows the operator to learn more about the robot and see for himself how the robot is built, something that deprives the whole thing about it being a robot.

> *Which type of factors are important to consider regarding safety, ergonomics and efficiency for implementation of a collaborative workplace?*

Safety is of course the absolute most important factor when it comes to collaborative working environments. The factors listed earlier in this report is crucial for the operator to be able to work with the robot and still feel safe. When to implement a collaborative robot you should focus on the assembly tasks that are bad ergonomically, partly because that is where the robot fits best, but also so that the operators does not feel that the robot is there to replace them, but to help them. This is also due to the efficiency of the robot. For the robot to be more efficient than the operator, it must work in a speed not allowed for a collaborative environment which then makes it non-collaborative.

> *Evaluate the possibilities for a collaborative workstation in the assembling of a fuse box.*

The possibilities for a collaborative workstation in the assembling of the fuse box are good, but not optimal. When one of the main driving forces for collaborative robots is the ergonomic benefits for the operator, the focus should be on the assembly stations where the ergonomic is bad, which it is not for the fuse box assembling, it is actually pretty good. The one thing that is bad ergonomically is the lifting procedure when to move the whole piece (including all cabling) to a carriage that is later moved to the assembly line. This is very heavy for the operator, but still something the robot cannot do due to its reach and payload capacity.

Another factor that makes this station unsuited to make collaborative is the amount of clamping and the handling of all cabling, something that the robot cannot do either, but which still takes up the main part of the cycle time. It is also a very small object to work on two at the same time (robot and operator) and you should therefor somehow separate their duties for it to be effective enough.

6.2 Summary

Human-robot collaboration is something that the industry can benefit from. By implementing this kind of automation, it is possible to eliminate none ergonomically tasks for the operator and at the same time increase the quality - a win-win situation. It is also important to keep the operators involved in the process and to let them know why the change is needed. By doing this everyone will be given a chance to feel more involved and that will ease the change in the process and minimize the risk of rumors and prejudices.

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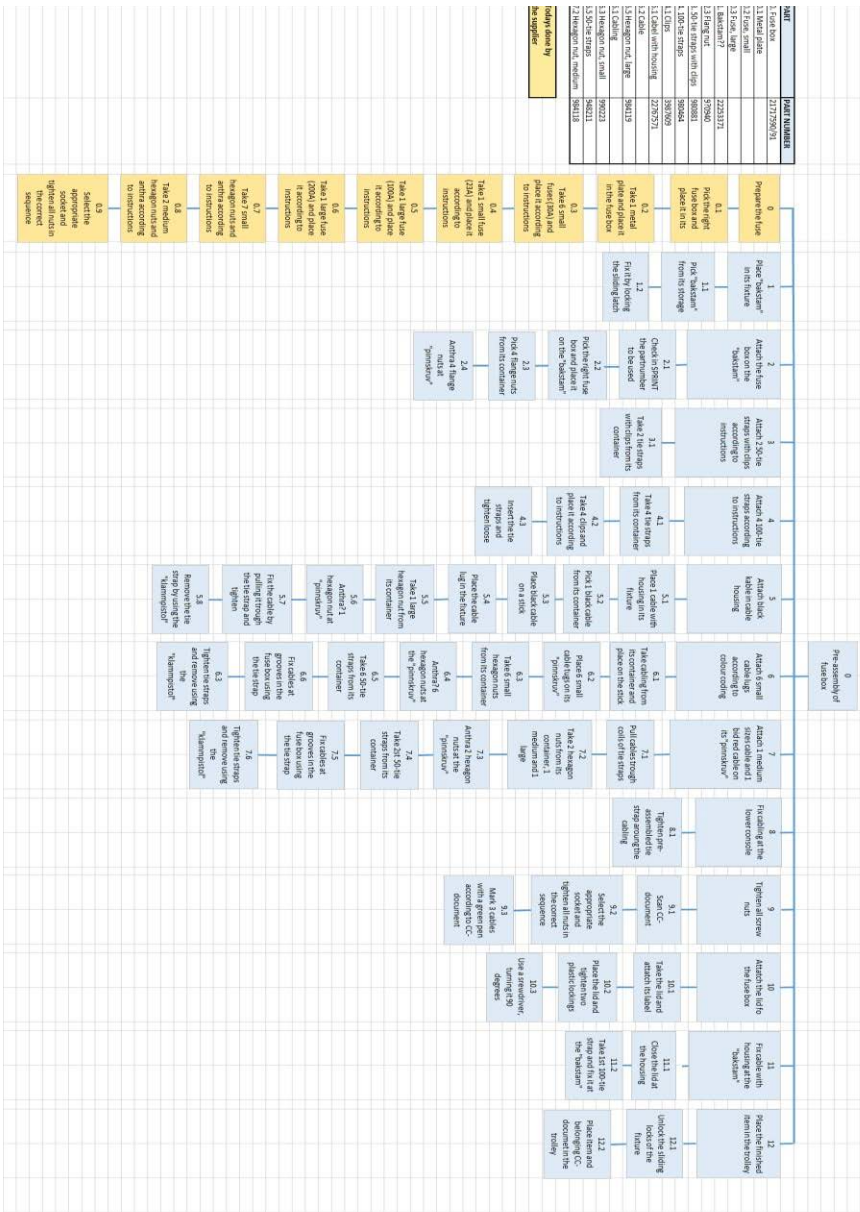
Appendices

Appendices 1: HTA – Hierarchical Task Analysis



Appendices 2: DFAA – Design For Automatic Assembly

Components	Part number	Turning	Orientation	Rugged details	Hooking	Centre of gravity	Shape	Weight	Length	Gripping	Assembly movements	Access	Fitting	Tolerances	Stick mounted details	Attachement method	Justering	Candidate for inclusion	Result (Points/Time)
Base obect-Rear plate	22253371	9/0	3/.1	9	3/.2	3	9/0	1/.5	1/.3	3/1.5	9/0	9/0	3/1.7	9/0	9/0	9/0	9/0	9	107/14.2
Fusebox	21717590/91	9/0	3/.1	9	3/.2	3	9/0	9/0	3/.1	9/0	9/0	9/0	9/0	9/0	9/0	3/.3	9/0	9	123/7
Metall plate	-	9/0	1/.2	9	9/0	3	9/0	9/0	3/.1	3/1.5	9/0	3/4.5	3/1.7	9/0	9/0	3/.3	9/0	9	112/13.7
Fuse, small	-	9/0	1/.2	9	9/0	3	9/0	3/1.5	9/0	9/0	9/0	3/4.5	3/1.7	9/0	9/0	3/.3	9/0	9	115/12.7
Fuse, large	-	9/0	1/.2	9	9/0	3	9/0	3/1.5	3/.1	9/0	9/0	3/4.5	3/1.7	9/0	9/0	3/.3	9/0	9	109/13.7
Flang nuts	9?0940	9/0	1/.2	9	9/0	3	9/0	9/0	9/0	9/0	3/0.5	9/0	9/0	3/0.2	9/0	3/.3	9/0	1	113/5.7
Hexagon nuts, small	990223	9/0	1/.2	9	9/0	3	9/0	3/1.5	3/.1	9/0	3/0.5	9/0	9/0	3/0.2	9/0	3/.3	9/0	1	101/8.2
Hexagon nuts, large	984119	9/0	1/.2	9	9/0	3	9/0	9/0	9/0	9/0	3/0.5	9/0	9/0	3/0.2	9/0	3/.3	9/0	1	113/5.7
Sexkantsmutter mellan	984118	9/0	1/.2	9	9/0	3	9/0	9/0	9/0	9/0	3/0.5	9/0	9/0	3/0.2	9/0	3/.3	9/0	1	113/5.7
Power cable, small	-	9/0	3/.1	9	3/.2	1	9/0	3/1.5	1/.3	1/.2	1/0.8	3/4.5	3/1.7	3/0.2	1/.4	3/.3	3/.1	9	65/24.7
Power cable, large red	-	9/0	3/.1	9	3/.2	1	9/0	3/1.5	1/.3	1/.2	3/0.5	3/4.5	3/1.7	3/0.2	1/.4	3/.3	3/.1	9	68/24.9
Power cable large black	-	9/0	3/.1	9	3/.2	1	9/0	3/1.5	1/.3	1/.2	3/0.5	3/4.5	3/1.7	3/0.2	1/.4	3/.3	3/.1	9	68/24.4
Power cable, red	-	9/0	3/.1	9	3/.2	1	9/0	3/1.5	1/.3	1/.2	9/0	3/4.5	3/1.7	3/0.2	1/.4	3/.3	3/.1	9	73/23.9
Cable with housing	22767571	9/0	1/.2	9	3/.2	1	9/0	3/1.5	1/.3	1/.2	9/0	9/0	3/1.7	9/0	9/0	3/.3	9/0	9	97/15.2
Fuse box	21717590/91	9/0	3/.1	9	3/.2	3	9/0	9/0	3/.1	9/0	9/0	9/0	9/0	9/0	9/0	3/.3	9/0	9	123/7
50-tie strap with clips	980881	9/0	1/.2	9	1/3,5	3	9/0	9/0	3/.1	1/.2	1/0.8	1/.7	3/1.7	3/0.2	9/0	9/0	3/.1	9	83/19.2
50-tie strap	948211	9/0	1/.2	9	9/0	3	9/0	9/0	3/.1	1/.2	1/0.8	1/.7	3/1.7	3/0.2	9/0	9/0	3/.1	9	91/15.7
100-tie strap	980464	9/0	1/.2	9	9/0	1	9/0	9/0	1/.3	1/.2	1/0.8	1/.7	3/1.7	3/0.2	9/0	9/0	3/.1	9	87/17.7
Clips	3987609	9/0	1/.2	9	1/3,5	1	9/0	9/0	9/0	9/0	9/0	9/0	3/1.7	3/0.2	9/0	9/0	3/.1	9	111/8.4
Lid, fuse box	-	9/0	1/.2	3	9/0	3	9/0	9/0	3/.1	9/0	3/0.5	9/0	3/1.7	3/0.2	3/.2	3/.3	9/0	9	97/10.4
Label	-	9/0	1/.2	3	9/0	3	9/0	9/0	3/.1	3/1.5	3/0.5	9/0	9/0	9/0	9/0	9/0	3/.1	1	101/.6
																		Sum:	2070/284.1

Index = 2070/3060 = 68%

Appendices 3: LoA – Level of Automation

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

LoA (current workstation)

LoA (fy)								
7								
6								
5								
4		1						
3		4						
2		2						
1		45						
	1	2	3	4	5	6	7	LoA (kog)

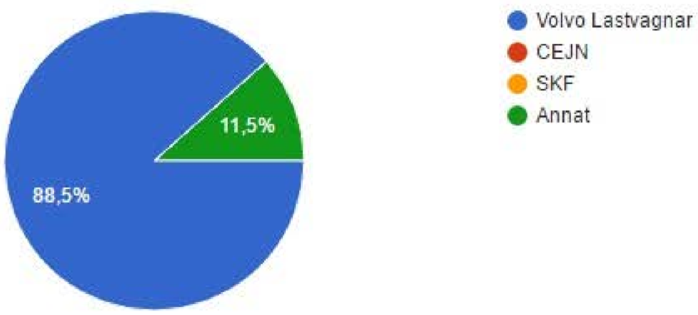
LoA (future workstation)

LoA (fy)								
7							16	
6								
5								
4								
3		4						
2		2						
1		32						
	1	2	3	4	5	6	7	LoA (kog)

Appendices 4: Survey

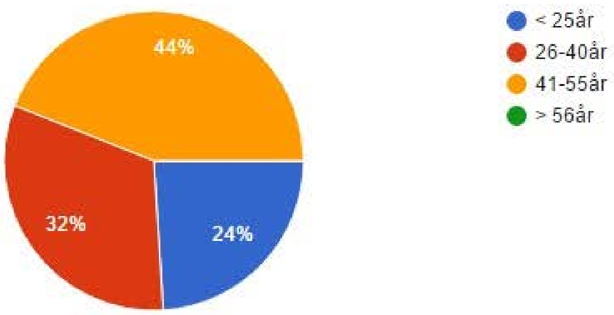
Vilket företag arbetar du på?

26 svar



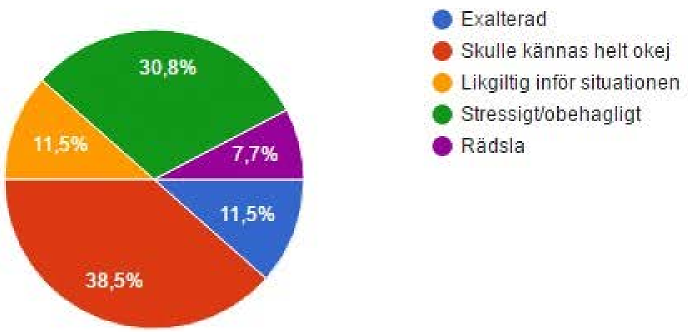
Hur gammal är du?

25 svar



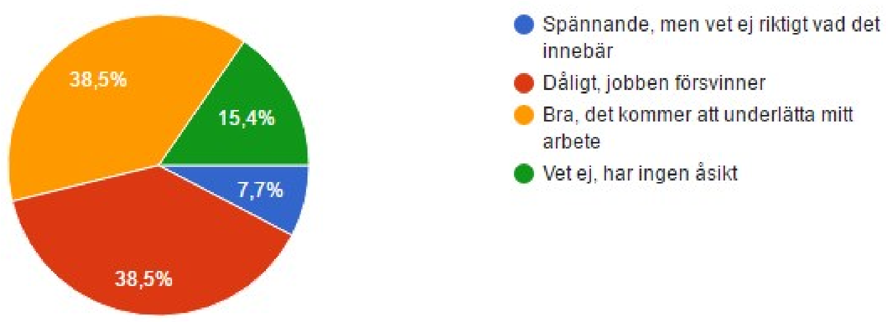
I videon ovan, hur skulle du känna om du hade tagit hennes roll?

26 svar



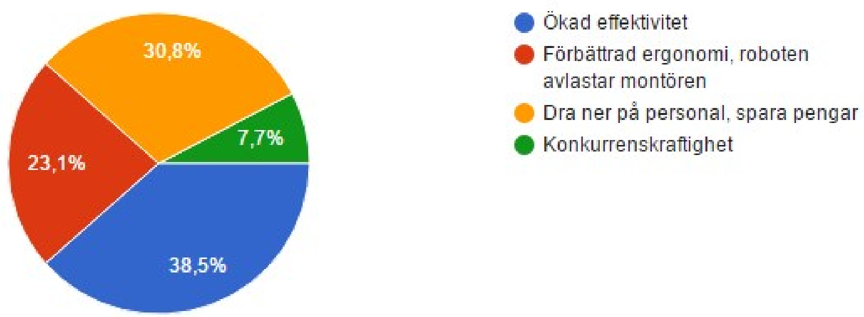
Vad tänker du när du hör orden automatisering och robot på ditt arbete?

26 svar



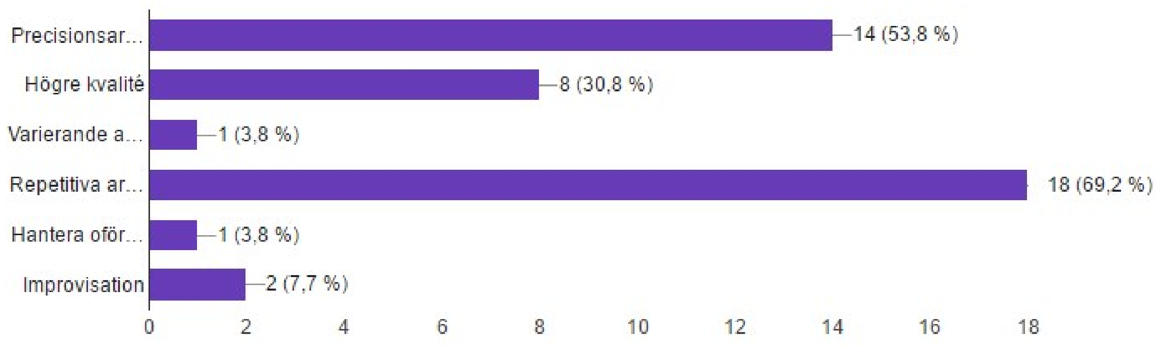
Varför tror du att företag väljer att automatisera sin produktion?

26 svar



Vad tror du roboten är bättre på jämfört med människan? (går att välja ett flertal alternativ)

26 svar



Appendices 4: SunriseWorkbench, programming example