Operator - Robot collaboration

Creation and evaluation of Operator - Robot work station

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Report Operator - Robot collaboration
Creation and evaluation of Operator - Robot work station
Team 2 Responsible for operator's workplace and design of AGC system
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Abstract

This thesis work was performed at AB Volvo Trucks at the department of Manufacturing Technology in the final assembly process. Volvo Group desires to implement new technology in their production plants to increase quality and efficiency as well as reduce ergonomic and safety issues.

The aim of this project was to design a collaborative workstation at Pilot Plant in Tuve for an operator, a robot and an AGC. The project originated from the station where the pushbuttons are assembled in the dashboard and on the basis of the current tasks, a new workstation was developed.

The thesis work was divided into two separate parts where one part was responsible for the robot and its programming. For further details about the robot's tasks, we suggest reading the thesis produced by Isak Abrahamsson and Simon Johansson. This report will focus on the operator's workplace and the design of the AGC system.

The project consisted of a status analysis, a task allocation between the resources, the design of the layout and AGC-system as well as the programming. Safety is one of Volvo's core values, which resulted in it being an important factor during the project.

The fact that the robot was not collaborative has influenced certain factors like the safety around the operator and design of the layout.

In order to implement new technology in production plants, it must be ensured that technology can perform the required tasks and that they contribute to a better working environment for the operator.

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0.2 Abbreviation

AGC - Automated guided chart; a small, driverless truck.
Current station - the real station found in Volvo's Production Plant.
FH/FM - Two of Volvo's truck models that are manufactured in the Tuve plant.
Future station - the test station developed in this project.
HMI-panel - The Human Machine Interface panel. It is located in the middle of the truck's cabin, right next to the driver.
Mir 200 - the brand and model number of the AGC.
SICK - High technical company that develops intelligent sensors.
SID/CP - The radio and climate control panels. They are both attached to the HMI-panel.
SOB - Instructions for work tasks and assembly used by Volvo.
Switch Calc - Volvo's it-system for positioning push buttons.
QULIS - Volvo's system for logging errors in production.

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Introduction

The introduction provides all the background information of this thesis, including aim, limitations and research questions.

1.1 Background

The robot and AGC are widely featured in a world of concepts like digitization, Industry 4.0 and Internet of Things. The robotics nowadays have the ability to work safely along side humans, also known as collaborative robots. The AGC is mainly used for internal material handling for more efficient and autonomous logistics. Both of them are parts of the future automation, including final assembly.

For a successful interaction between collaborative robot, AGC and human, the task allocation is very important. The human is better at flexible tasks and quickly takes her own decisions based on experience. The robot, on the other hand, is excellent at performing high-precision repetitive and monotonous tasks. The AGC is capable of managing tasks that are non-value contributing which the operator otherwise is forced to perform, such as moving materials between stations or collecting material. Together they can perform many tasks in a more ergonomic and safe manner. In this way, the cooperation can develop the final assembly by raising its level of automation. Cooperation with a collaborative robot and an AGC can facilitate the operator, increase production efficiency including saving time and money. By having the robot doing tasks that are critical in ergonomic and quality, these problems could be solved as well.

The final assembly at Volvo Trucks is a demanding process with low levels of automation and a high degree of product variations (Volvo, 2018). Previous projects have been made in the area of collaborative robots but the search for a suitable application continues. To improve quality, ergonomics and efficiency of the final assembly, a proposal is to increase the automation level by further investigate the possibility to use collaborative robots and driverless trucks integrating with the human. For Volvo's part, the development of human and autonomous co-operation is an important step in implementing futuristic technology and further demonstrating a leading edge in the transport industry.

1.1.1 AB Volvo and Volvo Group Trucks Operation

AB Volvo was founded in 1927 in Gothenburg, Sweden, as a affiliate to SKF. One year later the first truck was manufactured. Volvo Group manufactures, except from trucks, also buses, construction equipment, marine and industrial drive systems. AB Volvo was purchased in 2017 to the Chinese company Geely. AB Volvo's mission and vision is to be the most desired and successful transport solution provider in the world. (Volvo, 2018)

Volvo Group Trucks Operations is responsible for the production of trucks, which today also includes Renault Trucks, Mack Trucks and as a part-owner of the Chinese Dongfeng Commercial Vehicles. Volvo Trucks is today the largest manufacturer of heavy trucks in Europe with their three core values; quality, safety and environmental care.

1.1.2 The pushbutton assembly

The workstation to be developed is the final assembly where the pushbuttons and SID-CP are installed in the dashboard in the truck cab. Each truck is customized and therefore unique, which means that there are unlimited ways to positioning the pushbuttons according to the customers requirements.

Each component to be used for this assembly is picked by an operator and placed in a box on a trolley. The operator checks that the chassis number matches Switch Calc, where the unique positioning of the pushbuttons are shown at an A4 paper which is used as an assembly instruction. A pick-to-light system helps the operator to pick the right component. The components are placed in the same box with the Switch Calc and handed to another operator. The assembly starts and the panel is placed in a fixture that that eases the assembly. A SOB is used to guide the operator through the assembly for the SID-CP and wiring loom. To provide power and signals to the pushbuttons and SID-CP, the wiring loom is installed at the panel and later connected in the truck cab.

The box of material is poured onto the workbench and sorted by the operator for easier overview. The pushbuttons assembles into the connectors and then into the various panels. There are guiding traces at the back of each pushbutton to assure correct assembly. The operator visually verifies her work and makes sure that the assembly is made correctly. The assembly frame is turned and the wiring loom is attached to the connectors and other components in need of power supply such as SID-CP. Pushbuttons and connectors are also assembled on to the outboard, inboard and lower panel with guidence by Switch Calc. Some buttons are hardwired, which means that they are assembled without connectors and straight into the dashboard, such as the warning lights.

1.2 Aim

The aim of the project is to design a collaborative working station for an operator, a robot and an AGC at Volvo Trucks Pilot Plant in Tuve. The station will be developed from the moment that the material is delivered to the station until the pushbuttons and SID-CP are correctly assembled on each part of the dashboard. The three resources should work as a well-functioning team. The project has been divided into two cooperative parts. These two parts should be able to interact and contribute to an automated station design that meets Volvo's safety and ergonomic requirements in their final assembly. One part is about the robot and its programming. This report will focus on the operator's workplace which includes ergonomics, safety, tools and fixtures as well as a task allocation between the resources. The logistics around the work station will be processed and material delivery will be done by an AGC, which includes programming, layout and communication between AGC and operator.

The following step is to develop and implement a collaborative work station in Pilot Plant, a showcase for new technology to generate discussions and new ideas. The station is primarily intended as a test facility, but will hopefully answer the question whether it is possible to integrate the three resources and develop a well-functioning and safe work station. An important task is to evaluate the possibilities for team work between an operator and automation, since this is not a well-known subject in the industry.

1.3 Specifications of issue under investigations

The main question of the project:

- How is a safe and ergonomic collaborative system designed for an operator, an AGC and a robot?

The design of the operator's work station cover the following aspects:

Ergonomic: Aspects to ensure that the operator is working ergonomically must be taken into account.

Safety: The work station must be safe for the operator while integrating with the automation.

Tools and fixtures: The tools that the operator needs to perform the task will be specified. Fixtures should be designed and manufactured to facilitate the work for the operator.

Task allocation: Allocate workload and tasks between resources to get a well-functioning workstation.

The design of the AGC system cover the following aspects:

Layout: The layout for its working area will be designed to make sure that the AGC can move as safe and efficient as possible to complete its tasks. The AGC's route will be designed to deliver and retrieve material as smoothly as possible.

Tasks: The tasks assigned to the AGC will be specified.

Safety: The AGC must move safely to ensure no operator or property is harmed or damaged. Relevant ISO-standards will therefore be followed.

AGC programming: The AGC must be programmed in a specific interface to be able to complete its tasks.

Rack/trolley: The design of any rack and trolleys must be optimized to meet the ergonomic requirements of the working station.

Communication between AGC and operator: The communication between the resources will be developed and specified.

1.4 Limitations

The deadline for the thesis work is in mid June 2018. Due to time limitations the project will not focus on the factors listed below.

- An AGC, and therefore its interface, is chosen by Volvo Trucks on beforehand which means that it cannot be affected.
- The design of any components will not change during the project.
- The project will only focus on truck model FH.
- The different variations will not be taken into account. The focus is on a complete truck and assuming the existing components that are included. All material needed for the truck will be available in the station.
- How the buttons and their containers are packaged when delivered to the factory can not be affected. For example, how the different parts are separated with protective cardboard or similar material.

- Switch Calc, the existing it-system that presents information regarding the customized assembly, shall be used.

- At the start of the project, an area in Pilot Plant was assigned for the project. This site is selected by Volvo on beforehand and contains material for other production in Pilot Plant which can not be moved. Therefore, the possibility of designing the AGC's route is limited.

- The kitting for the control units for the radio and climate control will not be processed in the project. The associated programming will therefore not be included.

- Any evaluation regarding the possibilities for CE-marking of the designed work station will not be done.

- The developed work station will only work as a test facility and will not be implemented in Volvo's manufacturing process.

- Due to time limitations, another group is involved in the project which means that this report will not focus on the robot and its programming, the communication between the operator and robot as well as the robot's communication with existing it-systems.

2
Frame of references

In the following section, the frames of references for the project are specified.

2.1 The term Automation

Automation is a term used to explain that technology takes over a task that was initially carried out by a human (Fast-Berglund, 2017). It can be both physical (mechanical) and cognitive (information and system control). Physical automation is defined as the replacement of human muscle power by technology. Cognitive automation is defined as the amount of information the human needs in order to perform her task as well as the support in the form of instructions and tools required. Automation of processes and systems is a major part of Industry 4.0 and is used by companies who desire to improve their productivity. Within this there are many aspects, such as ergonomic advantages, time savings and quality improvements. All of this increases the competitiveness of companies and are therefore a relevant issue for future-orientated businesses.

2.2 Collaborative workstation

A collaborative work station is defined by a couple of resources, integrating with each other. The ISO-standard SIS-ISO/TS 15066:2016 general describes a collaborative workstation as:

"In collaborative robot operations, operators can work in close proximity to the robot system while power to the robot's actuators is available, and physical contact between an operator and the robot system can occur within a collaborative workspace." (SIS, 2016)

There is a scale of interaction between human and machine (Fast-Berglund, 2018). The interaction is greatest at the top and decreases step by step.

Human-Robot Collaboration - Human and machine performs the task simultaneously with the same product. Share the same workplace and work piece.

Human-Robot Cooperation - Human and machine perform the task simultaneously in the same area but not on the same product or component.

Human-Robot Synchronization - Human and machine have a common workplace. The planned interactive work is performed as much as possible in the same area.

Human-Robot Coexisting - Human and machine work side by side but do not have a direct common workplace or work piece.

2.2.1 Co-existing workstation

The definition of a co-existing workstation says that human and machine work side by side, but do not have a common work piece or workplace. Since they exist in the same time, however, they can still co-operate and e.g. supply each other with material. By creating a circular flow for the material handling, the flow reduces unnecessary movements and saves time which is crucial in production. By doing this, the company's competitiveness will increase as time and money are two important aspects of production planning.

2.2.2 Industry 4.0

Industry 4.0 is a future-orientated business model with fully automated systems within the company and between its suppliers. It is often thought of as an autonomous production plant with a very high level of information exchange between internal and external resources. The result is a boost in efficiency, reduced downtime and a better overview of the process from a management point of view. Implementation of Industry 4.0 can be divided into six steps, which are described as the "value-based development stages". (G. Schuh, 2017).

- Stage 1: Computerization.
- Stage 2: Connectivity.

Computerization and connectivity are two basic conditions that have to be satisfied before the transformation to Industry 4.0 can begin. Without a fully built-out computer network spanning across the entire process, in every level of the business, full automation is impossible to achieve.

Once the basic conditions have been met, the last four value-based development stages contain guiding principles on how to reach full implementation of Industry 4.0. The steps are building on each other, meaning that, for example, the features stipulated in stage 5 can't be implemented if the current development level corresponds to stage 3.

- Stage 3: Visibility. By collecting data from sensors mounted on various places in the process, it is possible to create a digital shadow of the actual plant. The purpose of the digital shadow is to assist in decision making, by continuously feeding real-time data to the plant management.

- Stage 4: Transparency. The collected data needs to be interpreted correctly if it is going to be useful. This is especially important when it comes to preventive maintenance, where a certain combination of parameters can indicate if a machine is nearing a break-down.

- Stage 5: Predictive capacity. Using the information obtained in stage three and four, the system makes predictions of the future. The different future scenarios are then ranked depending on their probability of occurrence. This further assists decision making by the management and limits the negative impact of for example a machine failure, since the problem can be solved at an early stage.

- Stage 6: Adaptability. The technology automatically adapts to changes in the business environment. It is for example able to make the decision to postpone the manufacturing of an order, based on information (obtained from the digital shadow) of an expected machine failure.

The proposed task allocation for the collaborative work station will have a positive impact on several of the development stages mentioned above. Even though full implementation of Industry 4.0 lies beyond the scope of this project, the increase in computerization and connectivity will help make it possible in the future. Concrete examples of benefits that come with the proposed task allocation are:

- The elimination of Switch Calc-documents in paper form will increase Computerization (stage 1). It will also improve Connectivity (stage 2), since Switch Calc will be communicating directly with the robot or the AGC, to make sure the right material will be picked, delivered and assembled in the right position.

- Having the AGC do the material handling will increase the operator's flexibility. Since she is not bound up with a non-valuing task like pushing a chart when collecting material for the assembly, she can focus on other tasks that are too complex for the robot and a circular flow for the station can be achieved during the desired cycle-time.

- By adding an electronic button that the operator presses when she has performed her tasks, the AGC receives verification that her work is complete and proceeds to the next task. This increases the operator's overview and the right to decide on the automated systems, giving sense of meaningfulness and control which are important aspects within the cognitive automation term. As a result the Connectivity and Visibility will increase, if a digital shadow is created and can be monitored by the operator.

- In the future, a robot can be placed on the AGC which will allow fully-automated material kitting and assembly of the final product. The kitting is now made by the operator and by automating it, the quality errors and ergonomic issues will be solved. Downtime for the process can therefore be reduced and unnecessary movements can also be eliminated.

2.2.3 HCA - Human Centered Automation

Human centered automation is an idea to make a safe, efficient and satisfying workplace for the human to work with automation. There are many different meanings of HCA depending on various time and in various context.

Some examples of relevant descriptions of HCA for this project are:
- Maintaining the human operator as the final authority over the automation.
- Allocating to the human the task best suited for the human, allocating to the automation the task best suited to it.

When implementing advanced automation in production, it is important to inform everyone involved in the process about the aim of the implementation. For a successful implementation of advanced automation there is one important aspect to take in to considerate; understanding of human behavior related to cognitive and psychical automation. (Sheridan, 1995)

2.3 Dynamo ++ method

A number of Swedish research groups have developed the Dynamo ++ method since the beginning of the 20th century. Dynamo ++ is a method that, in a structured way, maps a production section, to suggest possible automatons solutions to improve already existing assembly processes. Dynamo++ contains a number of methods, including HTA and LoA which will be used in this project.

2.3.1 Hierarchial task analysis - HTA analysis

A hierarchial task analysis creates a clear structure and flow of tasks to be performed in a workstation. The method developed in the early 2000's and the main elements are broken down into tasks and subtasks. The HTA-analysis forms a tree structure where its depth and width are analyzed. The greater the depth and/or width of an operation, the more complex the operation is. HTA-analysis gives a clear view over what is suitable to automate and what is not. HTA analysis is used as a support to LoA when evaluating a workstation.

2.3.2 Levels of automation

As mentioned in section 2.1, automation can be both physical and cognitive. To make the automation as effective as possible, a deeper understanding for both is required. This can be presented in a LoA-matrix which is based on a taxanomy that divides the physical and cognitive automation into seven levels. This means that there are 49 different types of automation solutions. The physical evaluation answers questions regarding how and to what extent the operator uses tools or machines in her work. The cognitive evaluation focuses on how much the operator must think by herself to complete the task and to what extent a system is guiding her through it.

2.4 Task allocation

A important part in this project is to perform a task allocation between operator, AGC and robot. The allocation should be made to achieve maximum utilization when it comes to safety, ergonomics and quality. There must be a cooperation between the operator and the automated systems to combine the differences.

2.4.1 The human

The human is sensitive, flexible and can act on unpredicted events. She can make fast decisions, remember a large amount of data and single out what she needs to use in the given situation. (Sheridan, 1995)

Advantage of a human:

- Detecting small amounts of visual, auditory, or chemical energy
- Perceiving patterns of light or sound
- Improvising and using flexible procedures
- Storing information for long periods, and recalling appropriate parts when needed
- Reasoning inductively
- Exercising judgment

2.4.2 The robot

The robot is fast, strong and effective. It has a huge advantage regarding humans in doing monotonously and repetitive work with great repetitiveness and position accuracy. It won't loose its temper and can store large amounts of data and then completely erase it after use. (Sheridan, 1995)

Advantage of robot:

- Responding quickly to control signals
- Applying great force smoothly and precisely
- Storing information briefly, erasing it completely
- Reasoning deductively
- Performing many complex operations at once

2.4.3 The AGC

The AGC is a Mir 200. It is a safe driverless truck that automates the internal material transportation. The robot optimizes work flows with high flexibility by smart technology. (ApS, 2017)

Advantages of the AGC:

- Eliminates bottlenecks in the material flow
- Allows operator to focus on high-value tasks
- Safely maneuvers around people and obstacles
- No changes in existing facility are needed (ApS, 2017)

2.5 AGC

The AGC has a local wi-fi which allows it to be controlled via a digital device. By connecting the device to the wi-fi, the AGC can be manually controlled with a joystick as well as navigating between positions set in a predefined loop. It is possible to create a mission, where the route is defined by the order of the positions and side tasks, as light or sound missions.

The AGC is equipped with two SICK safety laser scanners S300 (front and back) which gives it 360° visual protection around the truck. The laser scanners allows the AGC to read the area around itself. In order for the AGC to orient itself, a map is created by scanning the area while the AGC is manually driven with the joystick.

The position accuracy for the AGC is +/-50 mm for a defined position and +/-10 mm to a docking marker or charging station.

When the AGC is driven manually, it is completely blind. This means that it must be driven carefully and it does not have any brakes, so when the joystick is released, the AGC continues to roll a bit further in this driving mode.

When the AGC drives between two defined positions, it scans its path to calculate where it can go. If it detects an obstacle along the way, it seeks a new route to reach the desired position. It also tries to choose the shortest route, unless a preferred route is defined in advance.

A useful feature is Auto Detect which means that the AGC scans an item it has to dock to. The AGC stands in front of the object and scan it, and the feature allows the AGC to update its map and extract the exact coordinates for the object.

2.5.1 Safety requirements for the AGC

In order to the ISO standard SS-EN 1525 (Institution, 1997) a driverless truck must have certain safety features. Those relevant for this project are mentioned.

- Protection against unauthorized personnel
- Speed control
- Warning system
- Emergency stop device

- Detection on personnel in the travelling path

The ISO-standard for driverless trucks lists a number of corresponding requirements that the truck must achieve to be included in the standard (Institution, 1997). The most relevant hazards and corresponding requirements are listed below.

Hazard	Corresponding requirements
Crushing	- Braking system - Speed control - Personnel detection means
Falling objects	- Load handling
Movement without an operator	- Braking system - Steering system
Failure of control system	- Braking system - Protective devices
Insufficient ability to stop	- Braking system - Emergency stop device - Personnel detection means

Figure 2.1: Hazards and corresponding requirements for the AGC.

2.6 Ergonomic

A number of guidelines must be followed to develop an ergonomic workstation. These are taken from Volvo's Ergonomic Guidelines - Production 2017 (Volvo, 2017). The guidelines are based on a person's average length of 172 cm. The different areas of ergonomics are divided into green, yellow and red areas. Working in the green area means that the work is considered to be non-demanding and preferable. Work within the yellow zone is moderately demanding for the operator and should be further investigated. Working in the red zone is very demanding and should be avoided at all times.

2.6.1 Guidelines

The relevant guidelines for this project are listed below.

- For standing work, the green zone is estimated to be between 800mm and 1200mm from the floor.
- Compressive forces when pushing buttons with a finger is 16 N as long as 12 or less times per hour occur.
- Prolonged bending or stretching of the wrist can contribute to injury.
- The range of the operator is within the green zone at 290mm or less in dynamic work where the frequency is less than or equal to 30 times per hour.
- When placing information within the field of vision, the information should be placed at eye level. According to the standard, the height of the eye is measured in relation to the floor at a work station for standing work. For an average female, the optimal placement height is 1545 mm and the angle from the eye should be within 30 degrees.

2.7 Interview

There are three types of interviews:

- structured interview
- unstructured interview
- semi-structured interview

An unstructed interview is a method to gather information for further investigations. A small amount of questions are formulated on beforehand and based on the interviewees responses, a couple of follow-up questions are asked. Since the interviewees are asked different questions, the method lacks some precision and reliability, which is a disadvantage for the method. (*http://www.businessdictionary.com/definition/unstructured-interview.html*, 2018)

3 Methods

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

3.1 Methodology

The research procedure was conducted as an inductive study and an iterative process. The problem was identified, information was collected and analyzed and then conclusions were made.

3.2 Method selection

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

- Interviews and observations
- Hierarchical task analysis (HTA)
- Levels of Automation (LoA)
- Risk assessment

3.3 Status analysis

The current assembly station were observed to make a status analysis. This was made by filming the work process and discuss with the operators. To get a structured image of all tasks to be performed, the method for doing HTA-analysis and a sequence over the tasks were used. The HTA-analysis where evaluated and then further investigated to define the possibility to achieve a greater level of automation.

3.3.1 Quality and ergonomic analysis

The current sources of error and ergonomic problems were pointed out together with the teamleader during an unstructed interview. The knowledge about quality issues and critical ergonomic were used carefully later in the project to solve the problems and identifying possible improvements. To measure the compressive forces required to mount the pushbuttons in the assembly, a digital dynamometer of the brand Mecmesin was used.

3.3.2 Task allocation

The task allocation was preformed based on articles written on the subject. In collaboration with team 1, the task allocation was discussed to identify which tasks suited which resource best. To show this visually a sequence over the tasks were made and the resources divided into different colors.

3.3.3 Safety requirements

Before implementing new technology in production, a risk assessment should be made, not only for the automatic system itself, but also the environment in which it should be placed. This to illuminate what kind of risks to take into consideration when installing and programming the AGC. Each operation was analyzed and evaluated. The hazard identification process contains the risk that the task generates and what action is recommended to prevent harm to operator and material. The risk assessment was based on ISO-standards and were made on own experience. A full risk analysis must be done before the station can be implemented in the production environment.

3.4 Layout and design for the future workstation

There are many aspects to take into consideration when designing the layout for the new work station. In order to create the task allocation, the ergonomic and quality issues at the current station was analyzed. This was done by unstructured interviews with Volvo's ergonomist, the team leader and an operator at the station.

The task allocation was the basis when the logistics and work areas for the future station was created. A concept generation was made to discuss all types of solutions for the new work station. Together with the other group three concepts were made to create a possible safe and ergonomic work station. Since the robot was not collaborative the layout proposals for the workstation were limited. This is due to the fact that the robot could not work together or near the operator.

3.5 Layout and design for the AGC

The AGC was initially 38 cm high, which requires that it had to be raised to correspond to ergonomics requirements when the operator is to retrieve material. Therefore, a metal frame was built to reach the correct operating height. Dimensions of the finished construction are described in Result. A plastic board was mounted on the construction to allow fixtures to be bolted. A couple of fixtures was designed in Catia V5 and 3D printed. The fixtures were created for the HMI- and outboard-panel as well as for six hard wired buttons and later placed on top of the AGC.

3.5.1 AGC-programming

To get basic knowledge of the features for the AGC, the manufacturer Cobot held a half-day training. This was done in order to gain understanding of how the programming and the features of the AGC worked. When the AGC was unpacked, the emergency stop was mounted on top of it and the quickstart userguide was followed for boot.

The AGC was manually driven with the joystick around the area to create a map which was displayed on a laptop. When the map was finished, it was fine-tuned by wiping out unnecessary objects. After that virtual walls, preferred zones, sound and light zones were defined on the map. Later the different positions that the AGC should navigate between were defined as a loop in a mission.

3.6 Documention and demonstration

The pushbutton assembly were tested in the new collaborative workstation and the result was carefully evaluated. The task allocation, ISO-standards, ergonomics, safety and quality were important parameters for achieving a successful result. Both groups had a half-time reconciliation with Volvo to discuss if any changes needed to be made.

4
Results

In this chapter, the results of the methods will be presented.

4.1 HTA-analysis

The HTA-analys was made to analyze the depth and width of the workstation. The HTA for the current station (see appendix A.1) showed that step 2 - Assemble pushbuttons and connector and step 3 - Assemble components in panels were very deep. This sequence was therefore complex and had a potential to improvement. All assembly tasks in the current station are made by the operator.

As mentioned in limitations, no kitting for the material was included in the future station. Therefore, when comparing the current and future HTA-analysis, only the assembly part was of interest. Since the robot assembled all the pushbuttons in the future station, the operator will not be in charge of the pushbutton assembly anymore and therefore, that assembly is not included in the HTA for the future station. The tasks for the AGC are included in the HTA since it transports material between the robot and the operator. See appendix A.2.

4.2 Levels of Automation

Two different LoA-analysis have been made, one for the for the current station and one for future station, as shown in appendices A.3 and A.4. These only contains the assembly. The LoA-analysis for the current workstation showed that the automation level were very low. Since a robot and an AGC are used in the future station, the level of automation increases considerably. The work of the operator is done manually except for tightening of the screws which is done with a automated screwdriver.

4.3 Quality and ergonomic analysis

The interview with the team leader gave a number of sources of error and ergonomic problems that are common at the station. These are listed below and divided into quality and ergonomic.

Quality
Incorrect picking of material: Even though a pick-to-light system is used to

verify the picking of pushbuttons and connectors, human errors sometimes makes the operator pick another button or an incorrect number of the desired button. This makes the operator in charge of the assembly receiving incorrect material.

Button assembly at wrong position: Since many buttons have almost identical symbols, the assembly is hard for the operator. Sometimes a button is placed at the wrong position which can be hazardous if the truck driver thinks that a button has a special purpose and when pushed, something completely different happens.

Button have not been locked into the connector: Even though the buttons are placed at the correct position, the operator needs to verify that the buttons has locked into the connector. If not, the buttons will not be connected properly.

Ergonomics
Pushing the button into the connector: The force required to push the buttons into the connector varies, depending on if the button is a blind cover or not. The blind covers requires greater force than the buttons. This is a problem at the current station since the operators experiences ergonomic problems with their hands and fingers while working.

Material handling at the kitting: The design of the workplace requires the operator to bend far down to reach various components to be picked during the kitting. These components are located in the red zone for ergonomics and therefore affect the operator's body posture and work negatively.

Pushing a chart: To be able to perform the kitting, the operator pushes a chart in front of her. The chart weights a lot and is not optimal to maneuver, which causes the operator to face risks of ergonomic problems such as over effort and even squeezing damage.

Unnecessary movements: The logistics at the current station forces the operator to remove separative cardboard during her work hours, which causes unnecessary movements and becomes a malfunction for the operator. The operator also has to walk a long distance (<10m) when collecting the material. Both of the tasks are non-value-contributing work.

4.4 Co-existing workstation

The interaction between AGC and operator is Human-Robot Synchronization at the scale of interaction. Due to the robots limitations regarding collaboratively, the interaction between robot operator is co-existing. The result of the entire workstation is presented below. To get an overall picture of how the station is built, the robot's tasks are included and presented in task allocation and layout.

4.4.1 Task Allocation

The task allocation were based on some different aspects, the resources maximum utilization (mentioned in chapter 2.4), as well as the given problems at the workstation within quality and ergonomic.

Task for the human:
- Place SID-CP on the HMI-panel.
- Fasten the SID-CP with screws on the back-side.
- Place HMI-panel in fixture on the AGC.
- Place inboard panel in fixture on the AGC.
- Install the wiring loom.
- Start and stop the AGC.

Task for the Robot:
- Pick and place the switches upside down in the fixture. (Repeat x4)
- Assemble switches and connector. (Repeat x4)
- Place the prepared switches in the HMI-panel from behind. (Repeat x4)
- Place the prepared switches in the outboard panel from behind.
- Serve the operator with buttons.

Task for the AGC:
- Transport the panel to the robot's side of the station and back to the operator.
- Transport the assembled panels to the next station.

4.4.2 Quality and ergonomic

The new layout and work flow facilitated the work and enabled several of the quality issues and ergonomic problems to be solved.

Quality:
Incorrect kitting of material: The robot is now responsible for the kitting of the buttons. Since it picks buttons by position it always picks the right button.

Button assembly at wrong position: The robot is now responsible for mounting the buttons into the console. It always places the button at the correct position.

Button have not been locked into the connector: The robot is now responsible for the buttons to lock into the console. Since the robot always pushes with the same force, a force that is pre-measured to be sufficient for correct assembly, the buttons will always lock into the console.

Ergonomics:
Pushing the button into the connector: Since the robot is now in charge for pushing the buttons into the console, the operator will not be exposed to the ergonomic risks of the task. The power required to push the buttons in the connectors

with one finger was measured at 33.6 N for a button and 131.8 N for a blind cover. The result of the measurement exceeds the acceptable value of green ergonomics according to Volvo's Ergonomic Guidelines - Production as mentioned in 2.6.1. This proves that this assembly is harmful to the operator.

Material handling at the kitting: Since the panels now are located in green zone for ergonomic at the operator's workstation, the red ergonomics are eliminated.

Pushing a chart: Since the robot is responsible for the kitting of the buttons and the consoles, the operator will not have to push a cart in front of her, which eliminate the ergonomic risks with the task.

Unnecessary movements: Because the AGC will transport the finished dashboard to the next station, unnecessary movements for the operator are eliminated.

4.4.3 Co-existing tasks in workstation

There are two major co-existing tasks in the future work station.
In order to avoid material storage of buttons on both the operator and the robot area, the robot will serve the operator with buttons, place them on the AGC which drives them back to the operators side.
The operator places the panels on the AGC which then transport them to the robot for assembly. These two steps creates a circular flow where the resources supplies each other with material. This means that all three resources work together as a team.

4.4.4 Safety requirements

The ASA-analysis of the work station is presented below.

Task assignment	Risk/Hazard	Recommendation
The AGC stops next to the operator	- Collision with operator - Disturbance of AGC route	- A marked line on the floor which the operator should not cross - Use the AGC scanning system for avoidence of collision
The AGC transports the panels	- Material destruction if panels fall off the AGC	- Peg down the panels in fixtures on top of the AGC
Pause the AGC	- Forgetting to pause the AGC at the appriopriate position	- 3 secs of warning sounds to alert the operator
Play the AGC	- Forgetting to verify that the AGC can continue with its mission	- 3 secs of warning sounds to alert the operator
Unauthorized personnel in the working area	- Disturbance of the AGC-route - Collision	- Clear marking of the work area
Material residue on the factory floor e.g cable ties or screws	- Disturbance of the AGC-route - The wheels of the AGC can be harmed	- Clear the floor before starting the work
The built-up part on the AGC collides with an obstacle	- Collision	- Clear the area of any unnessecary material and obstacles

Figure 4.1: ASA-analysis of the work station

As shown in figure 4.1, the most common and predictable hazards are presented. A more thorough hazard identification should be performed before the workstation is implemented in the production environment.

4.4.5 Layout and design

The result of the layout and design for the future workstation is presented below.

4.4.5.1 Layout

The layout is divided into two different parts, a robot area and an operator area.

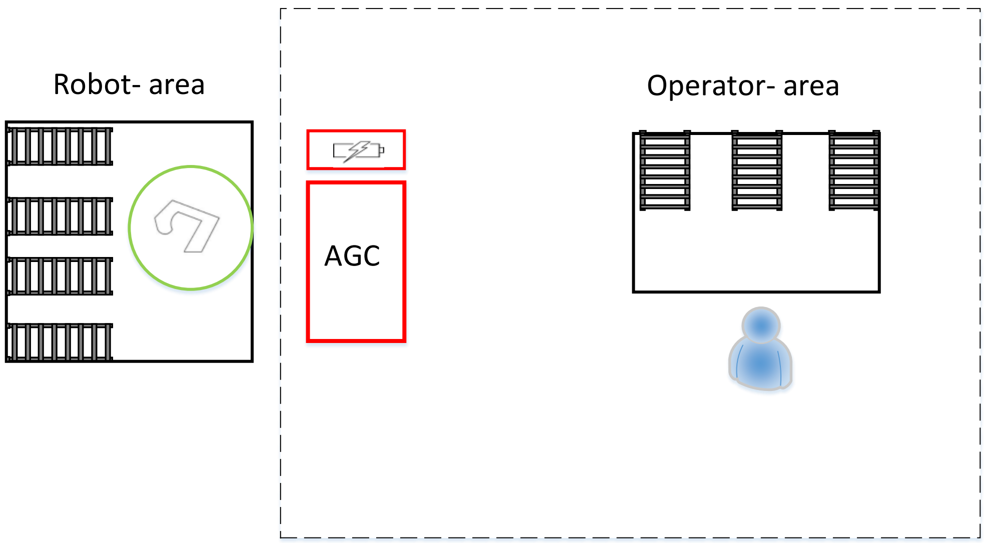

Figure 4.2: Layout of the work station

As shown in figure 4.2, the green area is the robot area, the black area is the operator area and the AGC is marked in red. The layout result for this report is presented as the area inside of the dashed line. The robot and the operator will work separately, with parallel tasks. The AGC works as a link between them.

4.4.5.2 Assembly sequence

The flow of the station is described with a process sequence with different colours for the three resources. The tasks for the robot are marked in green, the operators tasks are marked in blue and the tasks for the AGC are marked in red.

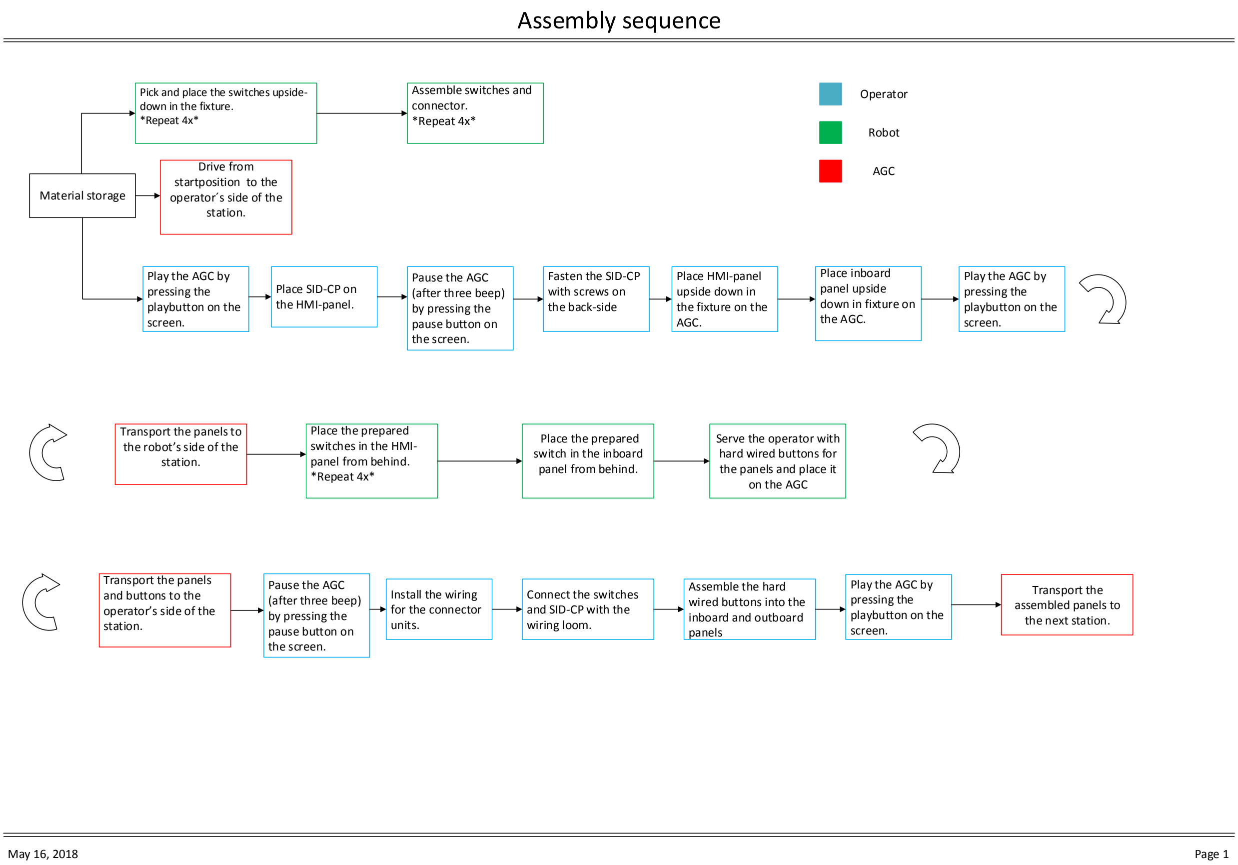

Figure 4.3: The assembly sequence for the future station with color coding.

The steps of the process sequence is described in text below.

1.1.1 The robot pick and place the pushbuttons upside down in the fixture. *Repeat x4*
1.1.2 The robot assembles buttons and connector. *Repeat x4*

1.2.1 The AGC drives from the start position to the operators side of the station.

1.3.1 Start the AGC by pressing the playbutton on the screen.
1.3.2 Place SID-CP on the HMI-panel.
1.3.3 Pause the AGC (after three beep) by pressing the pause button on the screen.
1.3.4 Fasten the SID-CP with screws on the back-side.
1.3.5 Place HMI-panel upside down in fixture on the AGC.
1.3.6 Place inboard panel upside down in fixture on the AGC.
1.3.7 Start the AGC by pressing the playbutton on the screen.

The steps above occur in parallel time.

2.1 The AGC transports the panels to the robot's side of the station.

2.2 The robot places the prepared switches in the HMI-panel from behind. *Repeat x4*
2.3 The robot places the prepared switch in the inboard panel from behind.
2.4 The robot serves the operator with hard wired buttons for the panels and place them in fixture on the AGC.

3.1 The AGC transports the panels to the operator's side of the station.
3.2 Pause the AGC (after three beep) by pressing the pause button on the screen.
3.3 Install the wiring loom.
3.4 Connect the switches and SID-CP with the wiring loom.
3.5 Assemble the hard wired buttons into the panels.
3.6 Start the AGC by pressing the playbutton on the screen.
3.7 The AGC transports the assembled panels to the next station.

4.4.5.3 Work area - operator

The operator's area is equipped with the materials needed for the chosen assembly sequence. A material shelf has been built to simulate the working areas in the production plant. The operator's work table is 880 mm high which meets the requirements for green ergonomics, according to Volvo's Ergonomic Guidelines mentioned in section 2.6. A screen is located 1545 mm from the floor and the angle from the eye is not more than 30 degrees, which meets the requirements for the green ergonomic zone.

The screen informs the operator how to assemble according to Switch Calc. In order for the operator to communicate with the AGC, an electric button is displayed at the screen. The button allows the operator to confirm that the AGC is in place and then send it to the next position.

4.4.6 AGC

The necessary features of the AGC are presented in the following text.

4.4.6.1 Design for the AGC

The construction build on the AGC is made from an existing pipe system for building the metal frame. It is 540 mm high and 710 mm wide and the pipes are connected with couplings. To ensure proper assembly of the construction on top of the AGC, it was screwed into the pre-drilled holes found on the AGC. These holes go down the chassis and allows the AGC to carry heavier weights.

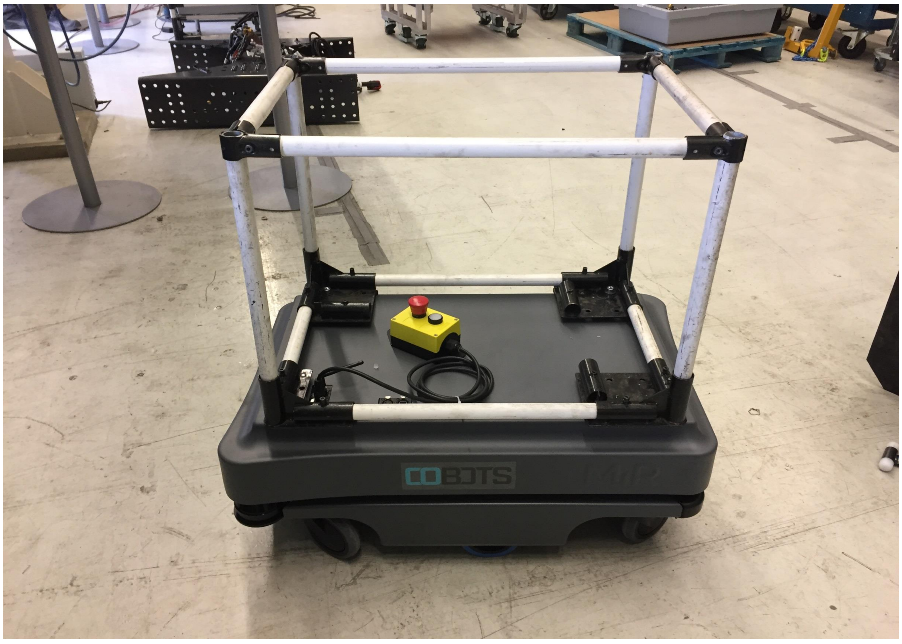

Figure 4.4: The construction on top of the AGC

On top of the construction a plastic board is placed. It is 890 mm long and 575mm wide. Four holes are drilled in the plastic board and a screw is pushed into each pipe. The holes and the screws makes it possible to move the plastic board, to meet the robot's requirements of position accuracy. The AGC has a positioning accuracy of +-10mm when docking to the charger station placed at the robot area. This is way to inaccurate for the robot. To solve this, the platform on the AGC was equipped with two positioning handles so the robot can move the plastic board a couple of millimeters in every direction.

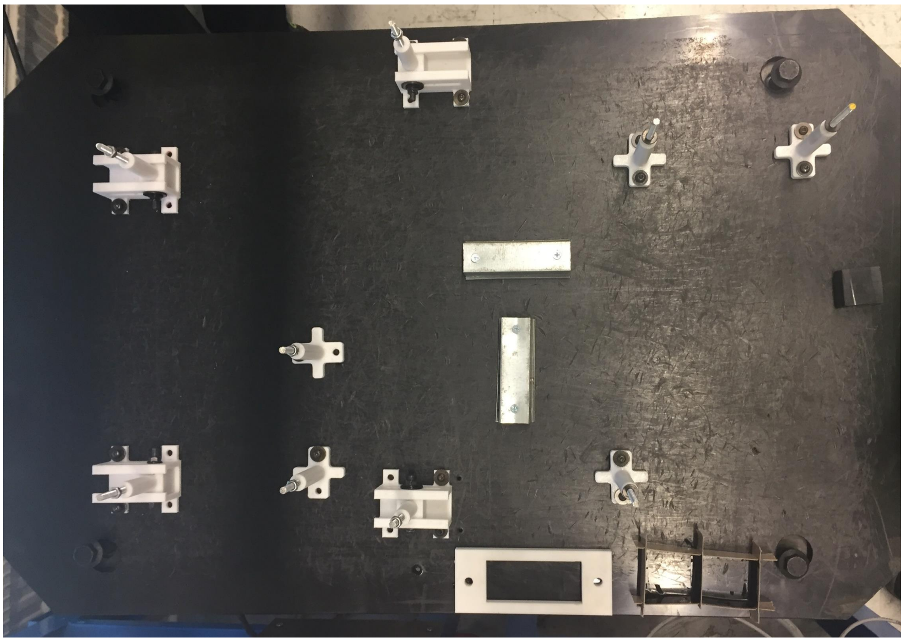

Figure 4.5: The various fixtures and the two positioning handles on top of the plastic board

4.4.6.2 Fixtures

The panels needs to be fasten onto the AGC. Therefore, a couple of fixtures were 3D-printed and screwed into the plastic board. The fixtures made sure that the panels stayed in position and gave support so they wouldn't bend. A fixture for the hardwired buttons was screwed on the plastic board, to make it easier for the robot to serve the buttons.

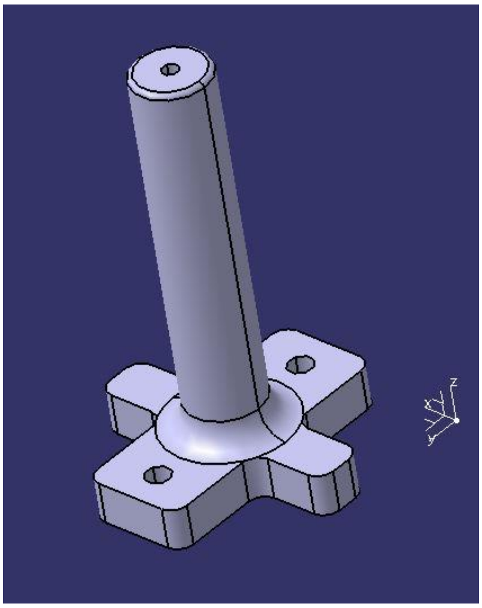

Figure 4.6: Fixture for panel designed in Catia V5

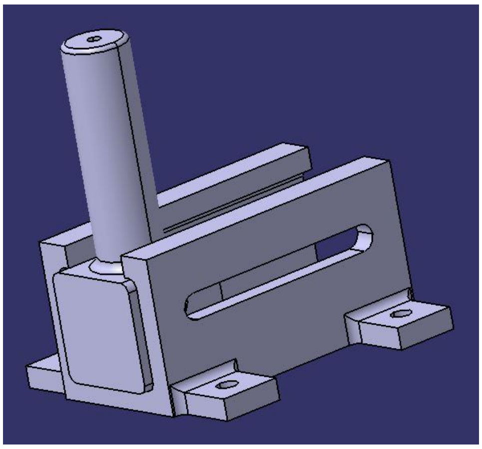

Figure 4.7: Adjustable fixture for panel designed in Catia V5

4.4.6.3 AGC-programming

The AGC drives into a predefined loop which was created through a mission in MiR's interface, where predetermined points such as positions and charging stations were defined in a certain order. In order to perform all tasks for the AGC, a map

of the area was scanned, see figure A.5 .
In the beginning of the work sequence the AGC starts from a starting position. When the mission has been started by the operator, the AGC drives to the operator's area. When it has reached the position, the AGC alerts the operator with sound signals and then waits for the operator to click pause. The operator stops the AGC and places the panels in the fixtures. Then the operator starts the AGC and send it to the robot's area.

The AGC leaves the robot station after a programmed waiting time, when all connectors are correctly assembled in the panels and the hard wired buttons are placed on the AGC. The AGC drives to the operators side of the workstation. When the panels are fully assembled by the operator, the AGC will transport the material to the next station.

5 Discussion

As mentioned before, the robot was not as collaborative as we first thought. The robot lacks many of the basic features a collaborative robot should have which makes it impossible for it to meet the safety requirements. It lacks power sensors, which should stop the robot if it runs into something or allows it to be stopped by the operators hand. The lack of safety features resulted in a co-existing workstation since the robot is not safe enough to work alongside or anywhere near the operator. Therefore, the resources had to be separated. The AGC is CE approved, which means it is safe to use and may be located within the operator's area. Therefore, it was possible that the AGC could stay close to the operator and that the operator did not have to keep an eye on the AGC while it was working. This, however, did not affect the task allocation for this project. Due to this, halfway through the project, the focus were on which tasks suited which resource.

If the robot were collaborative, and therefore safe enough for the operator, it is possible that another layout would have been chosen. In this case, the robot and operator would have worked at the same table and perhaps doing parallel tasks at the same work piece. If a successful assembly would have been achieved, the station would have been considered collaborative, instead of the current co-existing. This layout would probably have been better for achieving efficiency and meeting Volvo's desire to use future technologies in a innovative and competitive way. The AGC might have had another task if the robot were collaborative. If material kitting had been a part of the project, this would be an suitable task for the AGC. To assure that picking of material could be done by the AGC, some kind of facilities are required. A shooter solution or flow racks that change material when docking with the material shelf would probably be the best alternative. In that case, some of the quality and ergonomic issues would not exist. For example, incorrect picking of material, unnecessary movements and non-ergonomic tasks.

When comparing the HTA-analysis for the current and future station, it was noted that the assembly procedure was significant shorter on the future station. This is since the future assembly is done by the robot and it pushes the four buttons into the connectors in one step. As previous said, the robot is not included in this project. Therefore, and since this assembly process is chosen, the tasks for the AGC and the operator are quite few. The main task for the AGC is to transport material. The operator has two main tasks which are to control the AGC and assemble the components that are too complex for the robot to handle. The more complex assembly is done in the current station and has quite few ergonomic and quality issues.

One question to continue investigating is how the operator perceives to work as close to the AGC as she does at the moment. The controlling of the AGC is a brand new task for the operator. To make sure that the operator is comfortable with interacting with the AGC, the psycho social aspects of the work should be investigated. This is to validate that the operators work is not negatively affected by the controlling of an autonomous system. It can be problematic, since the human-machine interaction is not fully investigated in this project. Furthermore, the risks for stressing the operator by adding the AGC to the work station, is an important issue to take into consideration before implementing the mobile robots into the production plant. The stress would probably be relieved if proper information and education were given to the operators in beforehand.

By dividing the assembly into three parts, one for each resource, the station is easier to overview and better balanced, as the operator is not responsible for the entire assembly anymore. Together the robots relieve the operator considerably and increases the level of automation at the station, which is desirable to further increase the implementation capabilities of Industry 4.0.

6
Conclusion and recommendation

This part answers the question formulated in the beginning of this project.

6.1 Questions answered?

The main question of the project:

How is a safe and ergonomic collaborative system designed for an operator, robot and an AGC?

Safety is a very important part when it comes to implementing new automation such as robot and AGC in production environments. The operator will not work near the robot, which ensures the operator's safety. To implement this layout in the production plant, a deeper safety investigation is required.

As shown in section 4.4.2, the two separate groups have together solved many of the ergonomic and quality issues encountered at the workstation today.

The task allocation visualize which tasks are best suited for which resource. When implementing new technology, the company should focus on the assembly tasks that are critical from an ergonomic perspective. The robot will therefore assembly the buttons in the connectors and in the panel. AGC will manage the transport between the two work areas.

In order for the operator to feel comfortable with working with the automation, further investigation is needed on the operator's experience.

Aspects of design for the operator workstation

Ergonomics: Ergonomics at the workstation is noticeably improved since the robot now manages the kitting of the pushbuttons and the subsequent pushbutton assembly. The work height for the operator is improved as it is restricted to Volvo's ergonomics standard. As the AGC manages all material supplies, the undesired critical ergonomics are eliminated.

Safety: The safety at the workstation has been improved as there is a risk of clamping damage when handling the material trolley, which now is the case in the current station. Thanks to the AGC's safety features, it can work close to the operator without jeopardizing the operator's safety. At the same time, its safety features avoid any material destruction.

Tools and fixtures: The tool used at the workstation is a digital screen to ensure that the operator has access to the features required to control the AGC. The fixtures have been designed to the required height to ensure that the operator's operation height is approved when the panels are fixed in the fixtures.

Task allocation: The tasks that are too complicated for the robot and the AGC were assigned to the operator. This is due to the operator's ability to perform complex operations, her flexibility and ability to make her own decisions.

Aspects of design for the AGC system

Layout: The layout of the AGC route is carefully designed to suit the production environment to which the project has been assigned. The route that the AGC drives is a test run for the area in Pilot Plant.

Tasks: The tasks that the AGC performs are limited to material handling since it is the resource that best performs these tasks.

Safety: The AGC is CE-approved and equipped with an emergency stop. In addition, the operator has authority over the AGC system and controls the AGC by using an electric button on the screen located at the operator's workplace.

AGC-programming: The programming of the AGC is made through MiR interface. Various features have been used to get the AGC to perform its tasks.

Rack/Trolley: The construction built on top of the AGC is not CE-approved which means that it is not suitable to enter the production environment. This need to be taken into account and be further investigated before implementing the AGC in production environment. Since the AGC does not have access to any information about its height, caution should be exercised during test run.

Communication between AGC and operator: In the Mir interface, a dash board for the operator has been created where the functions required to control the AGC are built-in for easier monitoring. The AGC alerts the operator with warning sounds and a screen is used for easier overview.

6.2 Summary

Companies today are uncertain of the new technology's field of application for achieving the best possible results. One major question is weather the technology is too innovative for application in today's industries. Companies want to simplify the work of the operator and thus improve ergonomics. Quality of the product should increase by reducing human errors. By introducing human-robot collaboration, companies also ensure their status in the market as it is a relatively new area. In order for the implementation of new automation to provide a good result, all involved should demonstrate commitment to the change. The right automation should put in the right application, as all stations require individual automation solutions designed for the specific work station.

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A
Appendix

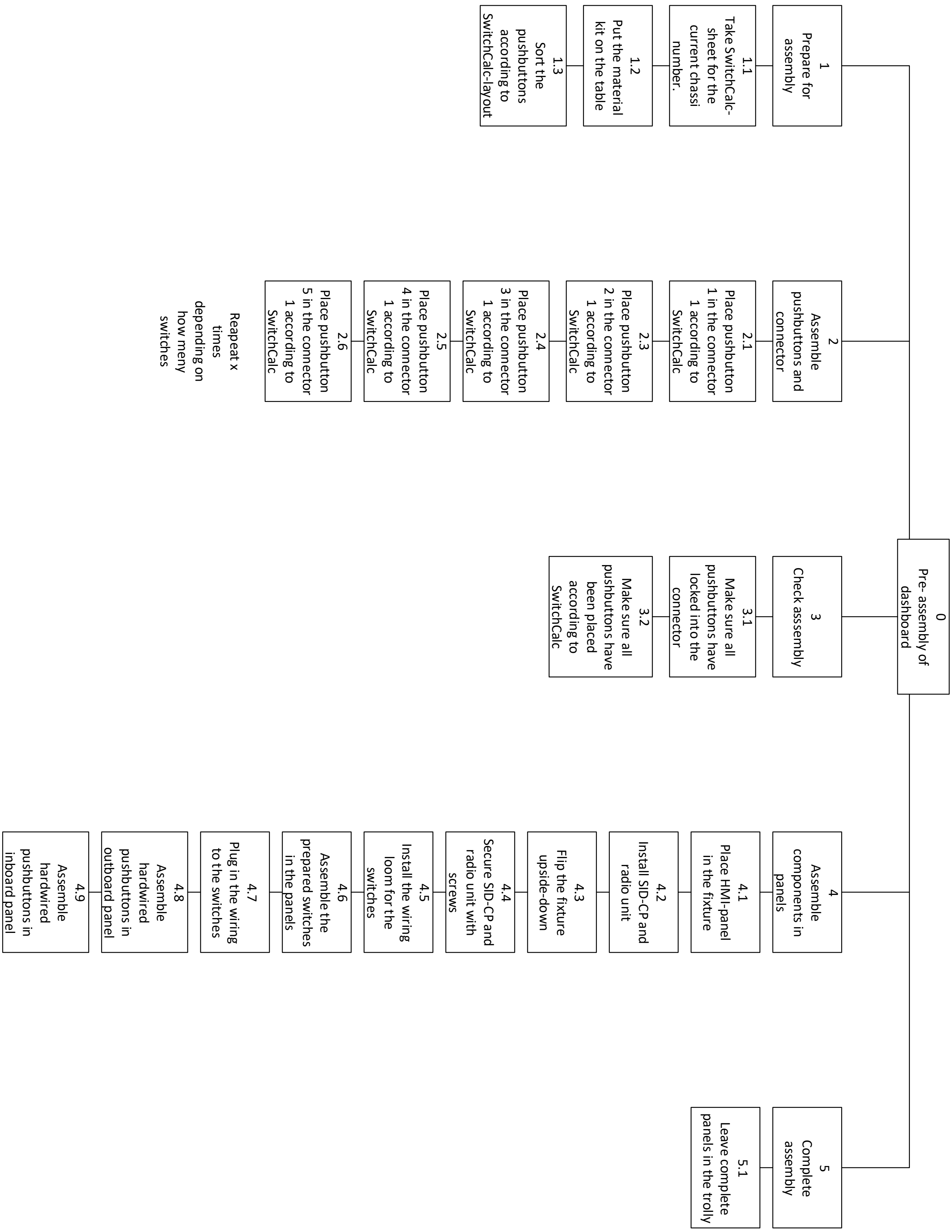

Figure A.1: HTA current station

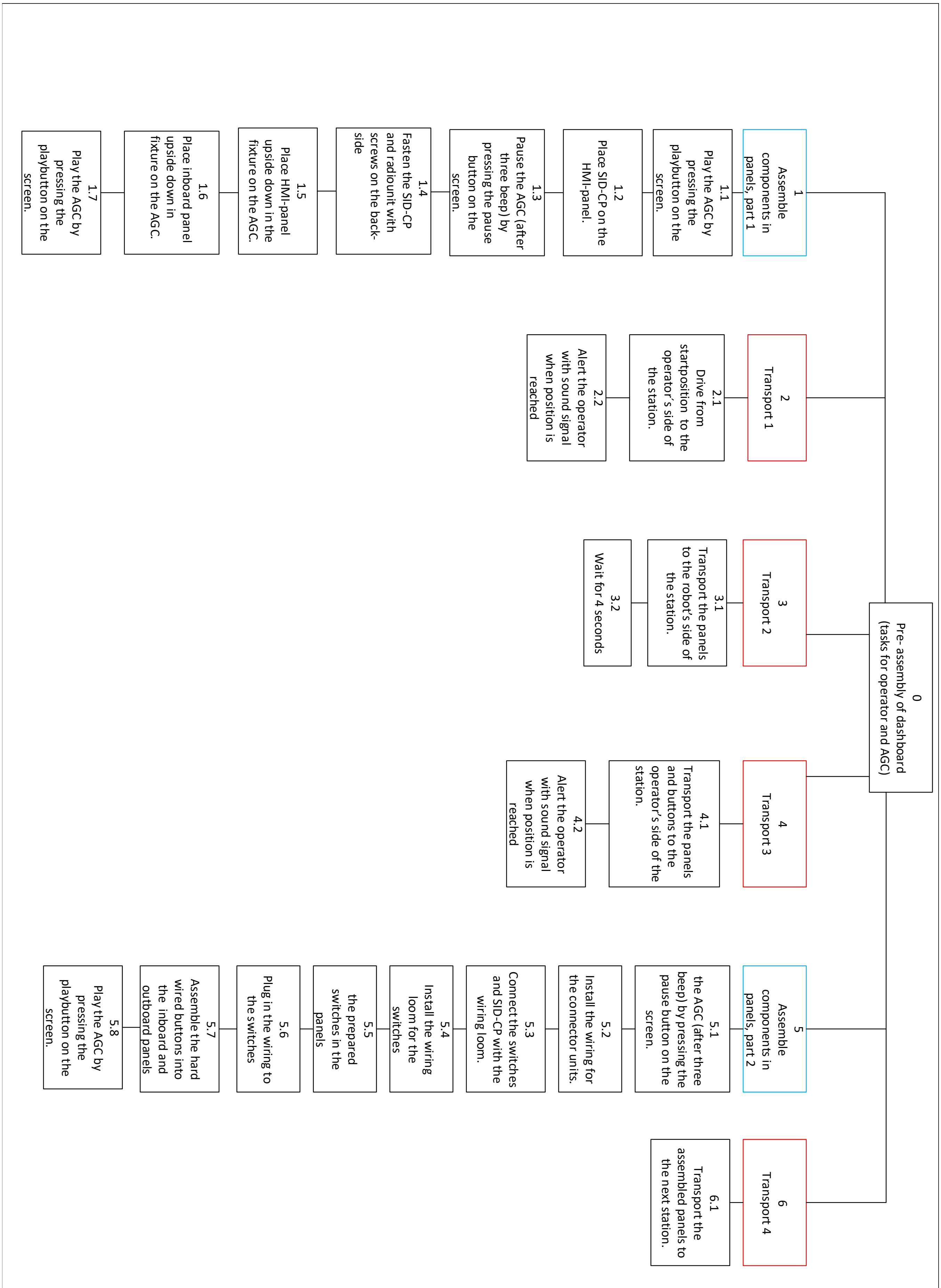

Figure A.2: HTA future station

LoA (physical)								
7								
6								
5								
4								
3	10	1						
2	2							
1	4							
	1	2	3	4	5	6	7	LoA (cognitive)

The current work operations for the operator	
1.1 Take the SwitchCalc-sheet for the current chassis number.	1.1
1.2 Put the material kit on the table.	1.1
1.3 Sort the material (buttons) according to the SwitchCalc-layout	1.2
2.1 Place button 1 in the connector 1 according to SwitchCalc.	1.3
2.2 Place button 2 in the connector 1 according to SwitchCalc.	1.3
2.3 Place button 3 in the connector 1 according to SwitchCalc.	1.3
2.4 Place button 4 in the connector 1 according to SwitchCalc.	1.3
2.5 Push on all buttons until they snap into the connector.	1.1
3.1 Make sure all buttons have locked into the connector.	1.1
3.2 Make sure all buttons have been placed according to SwitchCalc-s	1.3
4.1 Place SID-CP unit in the HMI-panel	1.3
4.3 Flip the fixture upside-down.	1.3
4.4 Secure the SID-CP with screws.	2.3
4.6 Push the connectors with buttons into the dashboard.	1.3
4.7 Install the wiring for the connector units.	1.3
4.8 Plug in the wiring to the connector units	1.3
5.1 Place fully assembled dashboard panels in a chart	1.2

Figure A.3: Levels of automation - current station

LoA (physical)								
7							4	
6							5	
5								
4								
3								
2			1					
1			10					
	1	2	3	4	5	6	7	LoA (cognitive)

Tasks for the resources	
1.1 Pick-and-place the switches upside down in the fixture. *Repeat x4*	6.7
1.2 Assemble switches and connector. *Repeat x4*	6.7
2.1 Drive from start position to the operator's side of the station.	7.7
2.2 Transport the panels to the robot's side of the station.	7.7
2.3 Transport the panels and buttons to the operator's side of the station.	7.7
2.4 Transport the assembled panel to the next station.	7.7
3.1 Press the pause button to stop the AGC	1.3
3.2 Place the SID-CP on the HMI-panel	1.3
3.3 Fasten the SID-CP with screws on the back-side	2.3
3.4 Place HMI-panel upside down in fixture on the AGC	1.3
3.5 Place inboard panel upside down in fixture on the AGC	1.3
3.6 Press the play button to start the AGC	1.3
4.1 Place the prepared switches in the HMI-panel from behind *Repeat x4*	6.7
4.2 Place the prepared switches in the inboard panel from behind	6.7
4.3 Pick the hardwired buttons and place them on the AGC	6.7
5.1 Press the pause button to stop the AGC	1.3
5.2 Install the wiring for the connector units.	1.3
5.3 Connect the switches and SID-CP with the wiring loom	1.3
5.4 Assemble the hard wired buttons into the inboard and outboard panel	1.3
5.5 Press the play button to start the AGC	1.3

Figure A.4: Levels of automation - future station

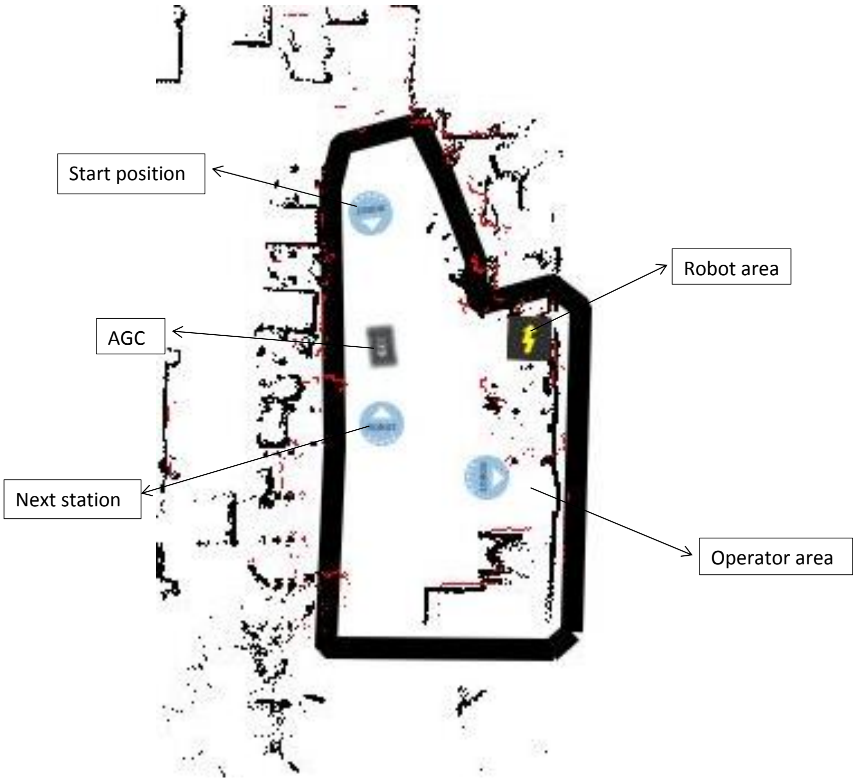

Figure A.5: A scanned map for AGC via Mir's interface