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Towards automated assembly of heavy duty trucks

A case study for finding better assembly tools

Master’s thesis in Production Engineering (MPPEN), Chalmers University of Technology, Gothenburg, Sweden

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Abstract

At Volvo Group Trucks Operations, a prominent manufacturer of heavy duty trucks, fulfilling the wishes of each customer is a successful business model. However, this business strategy has resulted in the company having approximately six-hundred truck variants. These variants are assembled in an assembly line divided into four areas responsible to assemble different parts of the trucks. The Base module area responsible for assembling the truck chassis is labor intensive with a high degree of product variation. Moreover, the truck chassis consists of heavy components and the assembly tools are also heavy. In recent years the company has experienced high labor turnover due to manual handling of heavy components and tools. Group Trucks Operations is therefore interested in investigating the suitability for improving the levels of automation in the truck chassis assembly line.

The purpose of this thesis is to examine the truck chassis assembly line to identify suitable areas for the study. Thereafter, apply the Dynamo++ methodology (Dynamic Levels of Automation for Robust Manufacturing system), REBA (Rapid Entire Body Assessment), and Analysis of perceived pain to measure the current levels of automation, the ergonomic conditions of the operators working in the selected areas, and the difficulty levels while they handle the tools and components respectively. Moreover, to give future improvement suggestions that improves the current levels of automation and the ergonomic conditions for those operators. Finally, communicate the requirements and benefits of the suggested improvements.

Application of the Dynamo++ methodology is based on the two triggers for change suggested by the company, which are to reduce the amount of manual work and improve the ergonomics.

The results are presented in short and long term case approaches with the conceptual solutions developed in each approach. The solutions include improvements of both mechanical and cognitive levels of automation.

Each conceptual solution is concluded with Hierarchical Tasks Analysis showing breakdown of tasks in the new system. Moreover, levels of automation matrices stand as end results showing improvements in the levels of automation from the current system.

The results obtained in this thesis give good understanding of using the Dynamo++ methodology. Additionally, the results give insight to the levels of automation concept and how to systematically increase or decrease them through generated ideas.

Keywords: *Levels of automation, Dynamo, Ergonomic, triggers for change*

Preface

To begin with, we would like to thank Group Trucks Operations for giving us the opportunity to perform our graduate thesis and providing us with the chance to deepen our knowledge in a field so fascinating and interesting to us as production engineers.

We would also like to express our gratitude to the production department at Group Trucks Operations Tuve Plant, particularly production managers, team leaders and operators in the Base module area. Their willingness and patience to answer our questions have helped us greatly throughout the thesis. They have provided us with needed information about the assembly procedure and thereby enhance our understanding. Thanks for making us feel welcome throughout our stay.

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List of abbreviations

DYNAMO	Dynamic Levels of Automation for Robust Manufacturing system
EDB	Engineering Data Base
FCS	Factory Control System
HTA	Hierarchical Task Analysis
JointCalc	Joint calculation
LoA	Levels of Automation
LoA_{info}	Level of Automation information
LoA_{mech}	Level of Automation mechanical
MONT/AAS	Assembly Assurance System
REBA	Rapid Entire Body Assessment
SoPI	Square of Possible Improvements
SPRINT	INTegrated PRoduction System
TfC	Trigger for Change

1 Introduction

This chapter starts with a background description of the thesis carried out at Volvo Group Trucks Operations (GTO). The company and its production plant in Tuve are briefly explained which is followed by the description of the thesis purpose, research question, delimitations and the thesis outline.

1.1 Background

Manufacturing technology has evolved towards mass customization where the customer demand has direct impact on the product design, fabrication, assembly, or distribution activities of the manufacturer (Coletti & Aichner, 2011). According to Bellgran and Säfsten (2010), the customer influence on the manufacturer's operational activities has resulted in increased system complexity. If a manufacturer fails in fulfilling the customers' demands, then the customers turn to a competitor. In this situation, the manufacturer strives to synchronize their products and manufacturing system with the customer demands (Fasth et al., 2010). Mass customization has resulted in high product variation because of the unique demands of every customer which requires flexible manufacturing system (Fasth et al., 2010). Additionally, the manufacturing system should be capable of delivering products in short lead time.

Striving for high system flexibility can be achieved through a hybrid manufacturing system which is assimilation between humans and automated systems (Krüger et al., 2009). A hybrid system combines the human's abilities to handle complex tasks and quickly adapt to new processes with the automation's abilities to perform heavy and repetitive tasks. Task division between humans and automated systems is a factor that changes frequently and is referred to as LoA (Parasuraman et al., 2000*)*. Identification and implementation of the correct LoA is necessary in order to achieve high effectiveness of the manufacturing system (Fasth et al., 2008).

GTO's business model is to satisfy their customers which resulted in the company having many truck variants. Today the company has approximately 600 variants where each one has many different components with heavy weights. The different variants are assembled manually in an assembly line with the help of heavy tools and equipment. Consequently, manual handling of heavy tools and components has led to high labor turnover which resulted in inexperienced workers schooling newly employed. GTO has therefore expressed concerns to examine the truck assembly line in order to select suitable area for the study. Moreover, evaluate scientific methodologies and tools suitable for improving the LoA in the selected study area.

1.2 Company introduction

GTO is an entity within Volvo Group organization which manufactures heavy duty trucks. The company was originated in the late 1920s in Gothenburg, Sweden and has production plants located in Belgium, France, Russia and South Africa as well. The production plants in Sweden are located in Umeå, Skövde, Borås and Tuve. The plant in Tuve is responsible for final assembly of the trucks. The plant employs approximately 1412 people during the year 2016 including 209 white collar workers and 1203 blue collar workers.

This thesis is carried out in GTO production plant located in Tuve, Gothenburg. It is therefore advised to neither confuse it with any of the production plants in Sweden nor in other parts of the world.

1.2.1 GTO Tuve plant

Figure 1 illustrates the layout of GTO Tuve Plant with workstations in the main assembly line and associated subassembly lines. The Plant is divided into four different assembly areas; Cab trim, Base module, Final assembly 1 and Final assembly 2.

- **Cab Trim**: The cab trim is divided into six parts responsible to do preparatory tasks which include dressing of the cabs before they are delivered to Final assembly 2, where they are mounted on the truck. The manufacturing of the cabs takes place in the production plant in Umeå before they are transported to the Cab trim in the Tuve plant.

- **Base Module**: This area is responsible to assemble the truck chassis. It is divided into four parts and consists of fifteen workstations. The assembly process for the chassis starts from placing the side rails on movable fixture followed by lifting and mounting operations of several components and ends as a finished chassis. The chassis is then transported to Final assembly 1 where it is merged with the axles.

- **Final Assembly 1**: This area is divided into six different parts and consists of workstations in the main line which are responsible for mounting the steering gear, suspensions, engine and axles after they are preassembled. The manufacturing of the engines takes place in the production plant in Skövde before they are transported to the engine and gear box assembly.

- **Final Assembly 2**: This area is also divided into six parts where mounting of the cab takes place followed by final testing, inspection, verification and adjustment of the truck.

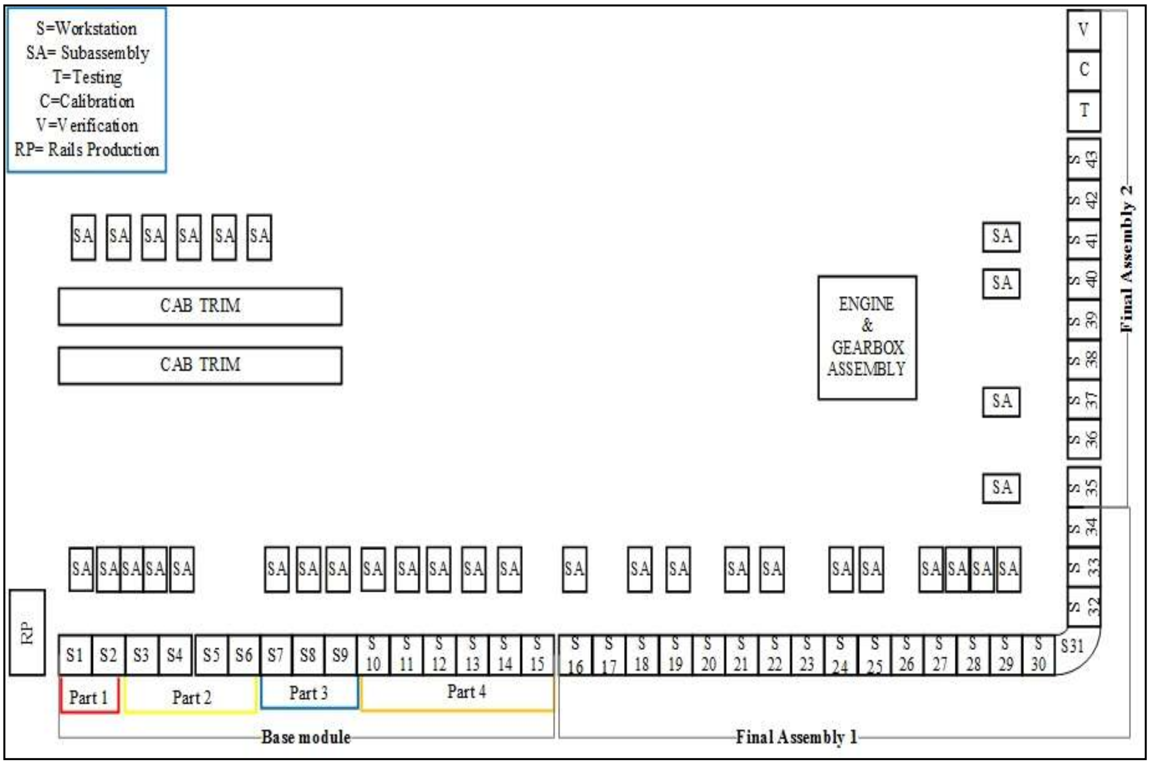


Figure 1: Layout of Tuve assembly line

1.3 Purpose of this thesis

The purpose of this thesis is to examine the truck assembly line to identify suitable areas to carry out the study. Thereafter, apply appropriate scientific methodology as well as other tools for acquiring knowledge for improving the LoA and the ergonomics at the identified areas and suggest improvements for the future. Finally, communicate benefits and requirements of the suggested improvements.

1.4 Research Question

To fulfill the purpose, this thesis will give answer to the following research question (RQ);

Is there a methodology which is effective for improving the LoA in the selected areas?

<u>**Motivation**</u>: The aim of this RQ is to investigate the feasibility of a method for improving the LoA of the selected areas. If the methodology proves to be suitable then it will provide GTO with the knowledge for improving LoA of other areas in the assembly line.

1.5 Delimitation

Before the project was initiated, project members and stakeholders discussed and decided on the following points to define the scope of this thesis;

- The application of the chosen methodology and other tools will only be at the selected areas.
- Handling of product specifications, redesigning components and CAD-drawings etc. are not included.
- If the LoA of a specific task cannot be increased due to the design of the product it will be stated. However, the project members will not look into how to change and document the product design in order to improve the LoA of that specific task.
- The supply chain of components to workstations by the in-house material handler is not included.
- Implementation of concepts developed from suggested ideas will not be carried out, but theoretical explanation of the concepts will be stated. Moreover, cost of tools and equipment proposed in the concept solutions will not be calculated.

1.6 Thesis outline

Chapter 1 of this thesis introduces the company and background to the problem handled. Moreover, the purpose, research question and delimitations are presented. Chapter 2 gives the theoretical frameworks needed for understanding the study. Chapter 3 explains the scientific methodology and other tools used during this thesis to give answers to the research question. Chapter 4 presents the empirical results and findings obtained by applying the chosen methodology and the tools. Chapter 5 discusses the results obtained in relationship to the theory, methodology and the tools used. Chapter 6 presents the conclusions of this thesis.

2 Theory

This chapter outlines the theoretical background of the thesis. Initially, the concept of automation is defined and then the LoA concept is explained. Thereafter, the Dynamo++ methodology is outlined followed by the explanation of the TfCs and an overview of the VASA model. The Chapter concludes with industrial automation case studies that exemplify automation solutions in assembly environments.

2.1 What is Automation?

Automation is derived from the Greek words "auto" -self and "matos" -moving, meaning "*acting by its own will, or by itself or spontaneously*" (Nof, 2009). From this standpoint, the definition of automation mainly concerns implementation of automated systems, such as robots and/or machines in the manufacturing that perform tasks automatically without involving humans. Automation par se is not only about installing robots and/or machines, but also to gradually improve tools and equipment used in the manufacturing.

In this regard, another definition of automation stated by Sheridan (2002) is the "*mechanization of manual processes*" which is also in line with the definition stated by Williams (2009), where automation is referred to as "*a way for humans to improve the capabilities of their tools and machines*". William (2009) further explained that "*it is the machine's capability to perform specific operations on external source's command*". With external source, the author is referring to the integration of control system with the robot and/or machines.

With this end in view, Chiantella (1982) and Williams (1999) classified automation in manufacturing as computerization and mechanization. Frohm (2008) shared the same view and elaborated on both classes of automation where mechanization refers to replacing human muscle power with improved machines and tools. And, computerization entails ease of human mental activity while handling information that controls manufacturing, Figure 2. As seen, the author gives a holistic view about automation in manufacturing by touching on the importance of improving the machines and tools as well as the information needed for controlling them.

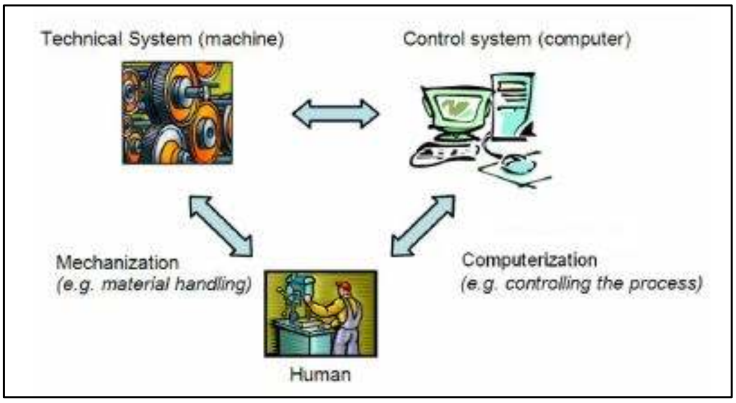


Figure 2: Mechanization and Computerization - Adapted from Frohm (2008)

2.2 Automate or not to Automate?

Automation is not the solution for every production environment, rather, a thorough study is required before application of automation strategies (Groover, 2001). The author elaborated that it is not feasible to automate if the costs are unjustified. In contrast, if automation proves to be an improvement in productivity, quality, labor performance and safety, efficiency and reduction in manufacturing lead time then it is justified to implement.

According to Kalpakjian and Schmid (2008) the development of computing machines and their control systems boosted the automation in manufacturing industry. The author stated that the reason behind integrating automation and technology with manufacturing is to increase productivity, quality as well as decrease cycle times and costs.

In a survey conducted by Frohm et al. (2006) about viability of automation most respondents linked the implementation of automation to that of lowering the number of employees in the production. Moreover, cost savings and achieving healthy working environment were other reasons for implementing it. The later reason was to reduce the physical and repetitive work in the production. In contrast, respondents argued that automation is not feasible in production environments with high product variation. Furthermore, they also reasoned against cases where automation results in high investments.

Although the authors above presented clear reasons for automating manufacturing processes, it can also be seen that striving towards automation might not be as straight forward and therefore requires considerations. Moreover, it can be seen that the authors agree on that if the implementation of automation results in higher costs then it is not advisable.

2.3 Assembly strategy

According to Rampersad (1995), assembly strategies can be classified as totally manual, semi-automatic, and totally automatic. In a totally manual assembly, all the tasks are carried out by the human using hands or with the help of tools. A semi-automated assembly is an environment where the tasks are divided between a human and an automated system whereas in a totally automatic assembly all the tasks are done by an automated system. Striving for a suitable assembly strategy for a specific product needs certain factors to be considered. In this view, Lotter et al. (2009) mentioned four factors, illustrated in Figure 3, that are important when determining assembly strategy for a specific product; these are:

- Variant diversity,
- Flexibility,
- Productivity and,
- Quantity

Figure 3 also shows the relationship between these factors and the type of assembly strategy that is suitable.

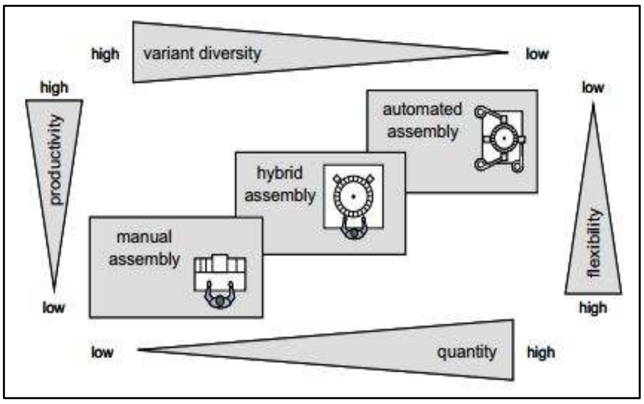


Figure 3: Automation strategy for assembly system – Adapted from Lotter et al. (2009)

Heilala and Voho (2001) also stated the following four factors for choosing suitable assembly strategy, illustrated in Figure 4;

- Number of variants
- Flexibility
- Batch size and,
- Production volume

These are similar to the factors mentioned by Lotter et al. (2009). The difference is that Heilala and Voho (2001) has divided automated assembly strategy into "*Flexible automation and fixed special purpose automation*". With flexible automation the authors mean the situations where the automated system is adjustable according to the need. Whereas, in fixed special purpose automation the automated system performs repetitive tasks.

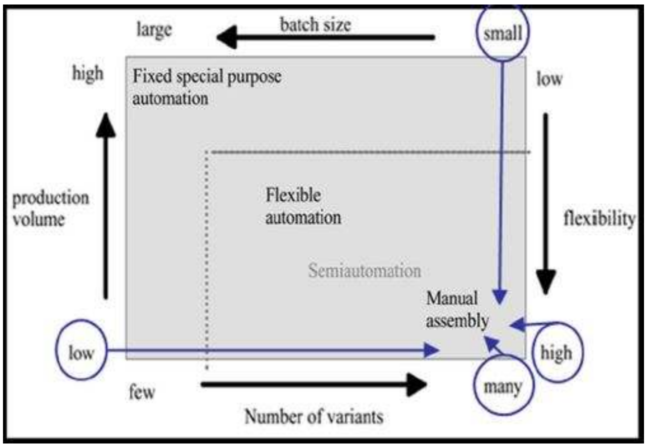


Figure 4: Automation strategy for assembly system – Adapted from Heilala and Voho (2001)

From the figures it can be seen that there is a relation between productivity, production volume, quantity and batch size because they concern the amount of products that are within the manufacturing system. These parameters also propose the same assembly strategy. For instance, if a manufacturer's aim is high productivity, quantity and large batch size then an automated or fixed special purpose automation assembly strategy is most suitable. On the other hand, there is a correlation between the parameters variant diversity, flexibility, and number of variants because they show the adaptability of the manufacturing system. If high variant diversity, high flexibility and many variants is the aim of the company, then a manual or hybrid automated assembly strategy is most suitable.

2.4 The LoA concept

The definition of the concept LoA has evolved since it was first defined by Bright (1958) on seventeen levels of mechanization depending on who initiates the control. The first four levels concern the human, level five to eight is the human together with the automation, and the levels nine to seventeen is the automation by itself. As seen in this definition, the author's focus is to replace the human muscle and mental efforts with the machine. It is observed that this definition is leaning more towards improving the LoA_{mech} and therefore a definition that is complete and includes more details is required.

Another aspect of the LoA concept is discussed by Parasuraman et al. (2000) where they defined it as *"The interaction and task division between the human and the machine should instead be viewed as a changeable factor which can be called the level of automation"*. In their perspective, the levels are leaning towards computerization of the tasks, where at the lower levels, the majority of the decisions are taken by the human and with an increase in each level the involvement of the computer in decision making increases. The definitions given by Bright (1958) and Parasuraman et al. (2000) give different perspectives of the LoA concept where Bright (1958) has defined the mechanical scale whereas Parasuraman et al. (2000) defined the information scale of LoA.

A recent definition of this concept is given by Frohm (2008), who defined LoA for manufacturing systems as, "*The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic*". In his definition, the physical task corresponds to the level of mechanization discussed by Bright (1958) and the cognitive task corresponds to the level of computerization mentioned by Parasuraman et al. (2000). It is observed that Frohm (2008) definition gives a better overview of LoA by considering both the LoA_{mech} and LoA_{info} simultaneously, illustrated in Table 1, which helps to achieve the right level of support for the humans in the manufacturing. The scales are based on the two classes of automation which are the Mechanization and Computerization mentioned in Chapter 2.1. The LoA_{mech} is used to assess the physical support like tools and equipment etc. and the LoA_{info} to assess the cognitive support like work instructions needed.

Frohm (2008) divided the levels on both scales into a seven step transformation, from total manual to total automatic. Both the LoA_{mech} and LoA_{info} are independent of each other. Suitable level for each scale is dependent on the need of physical and cognitive support that the human requires in the manufacturing environment. It is seen that the transformation of manufacturing system from total manual to total automatic for achieving maximum system robustness is not a single step endeavor. Rather, a stepwise approach is needed to progress from one level to another.

Table 1: Mechanical and information LoA Scales - Adapted from Frohm (2008)

LoA	Mechanical and Equipment (LoA_{mech})	Information and Control (LoA_{info})
1	**Totally manual** - Totally manual work, no tools are used, only the user's own muscle power. (e.g. User's own muscles 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. User's 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 instructions 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 user's 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 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 itself (e.g. Autonomous system)	**Totally automatic** - All information and control is handled by the technology. The user is never involved (e.g. autonomous systems)

The scales mentioned by Frohm (2008) are integrated using a LoA evaluation matrix (LoA matrix) given by Fasth et al. (2009), illustrated in Figure 5. The size of the matrix is seven by seven giving forty-nine different solutions of task allocation each including LoA_{mech} and LoA_{info}. Human or machine both have the opportunity to assemble or monitor tasks depending on the need and desire of the company. Each task obtained in the current system is compared with the scales and assigned a number from one to seven on both LoA_{mech} and LoA_{info}. The results of this activity are then plotted in the LoA matrix which gives information about the system's current LoA.

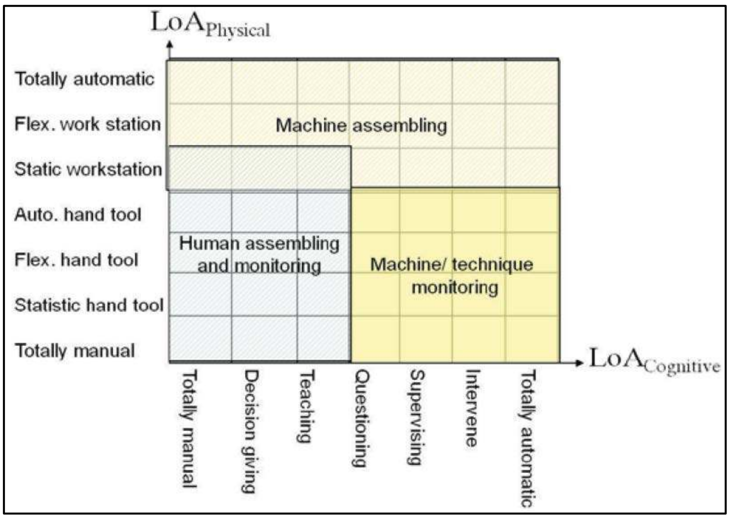


Figure 5: LoA Matrix – Adapted from Fasth et al. (2009)

In this thesis, evaluation of an appropriate scientific methodology that could be suitable for improving the LoA in the selected study areas is stated by GTO. For this reason, the Dynamo++ methodology was presented and chosen together with the stakeholders. Theoretical background of the methodology is explained in Chapter 2.5 and its application during the course of this thesis in Chapter 3.2.

2.5 The Dynamo++ methodology

The Dynamo++ methodology is used to find a new state of the automation in a manufacturing system, Figure 6. It is a method for changing the manufacturing system which firstly measures the current LoA of the system to gain knowledge if it is high or low etc. and then analyze appropriate LoA for the future (Fasth et al., 2008). It gives the perspective of the manufacturing company's current LoA and ways to change it based on the TfC which are the actual demands and needs of the manufacturer (Fasth & Stahre, 2013). See Chapter 2.6 for the TfC.

The Dynamo++ methodology evolved during 2004 to 2007 in collaboration with seven industrial companies, out of which six participated in developing it, and the seventh company was used for its validation. Dynamo++ has four phases and each phase has three steps. (Fasth, 2012)

2.5.1 Phase 1 - Pre study

The pre study phase includes following steps;

1. Select a system where the measurement is to be conducted
2. Walk-through the system to identify and document number of stations, possible bottlenecks, number of staff etc.
3. Do Value Stream Mapping (VSM) to map main operations and flow within the system

2.5.2 Phase 2 - Measurement

The measurement phase includes following steps;

4. Construct Hierarchical Task Analysis (HTA) to identify main tasks, subtasks and operations
5. Measure LoA both physical and cognitive in the system
6. Document measurement results

2.5.3 Phase 3 – Analysis

The analysis phase includes following steps;

7. Workshop to decide relative Min- and Max LoA for different tasks in the system
8. Design Square of Possible Improvements (SoPI) to find improvement possibilities for different tasks in the process
9. Analyze SoPI, how is it impacted when the measured values which are the current LoA, are moved around the square regarding the following parameters: cycle time, investments, layouts, competences, information needed etc.

2.5.4 Phase 4 - Implementation and follow-up

This phase includes following steps;

10. Suggesting improvements, that is, to write and/or visualize improvement suggestions based on the SoPI analysis and the company's wishes
11. Make the improvements in the system

12. Do follow-up in the system to see what effects the suggestions have had on time and flow parameters

The Dynamo++ methodology is iterative and the steps can be repeated until the desired results are achieved. In order to avoid over-automation and sub-optimization it can be combined with different scientific tools. (Fasth, 2012)

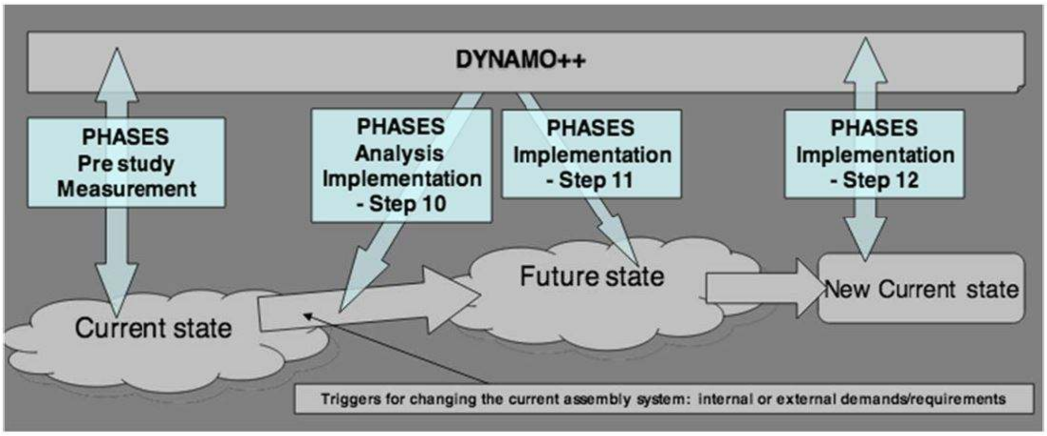


Figure 6: Phases of Dynamo++ Methodology - Adapted from Fasth (2012)

2.6 Triggers for change

The Dynamo++ methodology requires triggers for changing the current system which are the parameters that the company wishes to change. Some of the TfC, exemplified by Fasth and Stahre (2013), are improving quality, lower manufacturing cost and shorter manufacturing throughput time. In this thesis GTO aims to evaluate the Dynamo++ method using the following TfCs:

- To reduce the amount of manual work by shifting the tasks from the operator to other resources.
- To improve the ergonomic conditions for the operators by finding better assembly tools and equipment.

2.7 VASA model

Figure 7 explains the VASA model which is used to measure ergonomic impact due to material exposure in production environment. It assures that the appropriate working height is set for the material pallets so that the operator easily handles the components. In the model, the working height is divided into three categories which are red, yellow and green depending on the ergonomic impact. The most inappropriate heights for picking the components are classified as red which are the highest or lowest heights of the material rack. The heights classified as green are the middle section of the rack which is the most appropriate height for picking the components. (Backman, K., 2008)

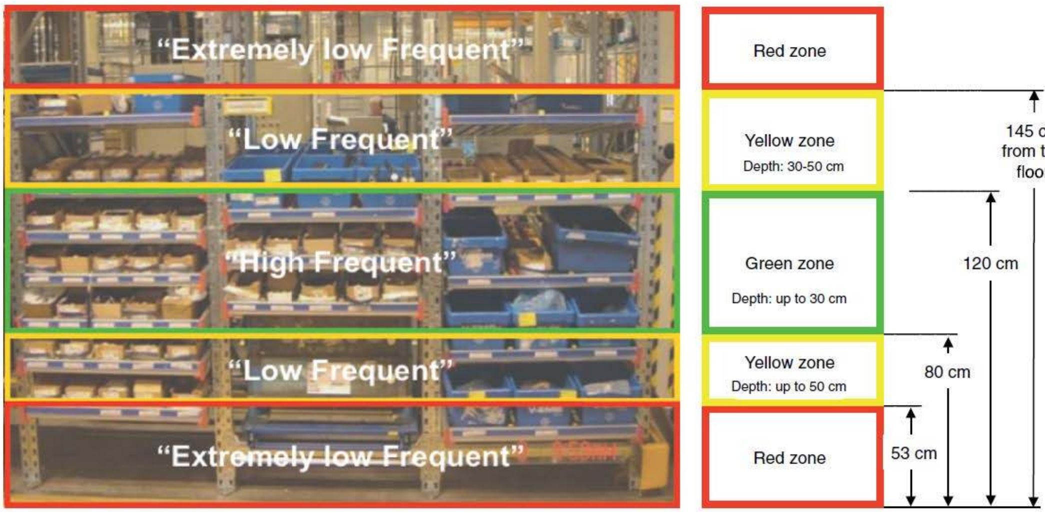


Figure 7: VASA model – Adapted from Backman, K. (2008)

2.8 Industrial case studies

A literature review aimed to highlight industrial automation case studies, focusing mainly on assembly environments, was carried out. The main goal was to gain knowledge about existing automation solutions in industrial environments.

2.8.1 Industrial robot

According to ISO 8373:2012 an industrial robot is defined as, "*Automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications*". The standard exemplified an industrial robot as one with sensors for visual awareness of picking and placing an object. Moreover, ISO 8373:2012 defined Human-Robot Interaction (HRI) as "*Information and action exchange through vocal, visual, and tactile means between human and robot to perform a task by means of a user interface*".

2.8.2 Human robot collaboration in assembly environments

Ore et al. (2015) carried out an automotive case study to verify collaboration between the human and robot in the assembly process of truck tire using simulations, Figure 8. The study compared three assembly situations; fully manual, fully automated and human-robot collaboration. In the later situation, the authors categorized the assembly tasks as heavy and high precision work. Then the tasks were distributed where the heavy work was assigned to the robot and the tasks requiring high precision were assigned to the human.

Figure 8: Simulation of HRI for assembling truck tire - Adapted from Ore et al. (2015)

Another industrial case study by Ore et al. (2014) focused on assembling flywheel cover, weighing 60 kg, onto an engine block, Figure 9. In this case study, the human-robot collaboration was done where the robot performed the handling tasks which included lifting, loading and holding the flywheel cover while the human controlled the movements of the robot with the help of force sensors.

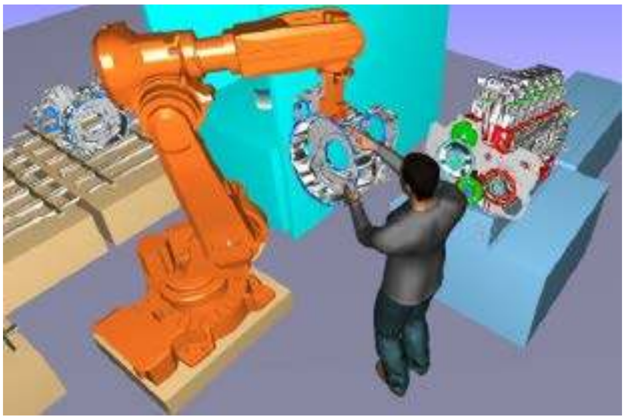


Figure 9: Simulation of HRI for assembling flywheel cover - Adapted from Ore et al. (2014)

Busch et al. (2013) discussed human-robot interaction to improve ergonomic conditions for the operator performing welding, Figure 10. In this study, the labor intensive manual tasks which included picking, positioning and holding heavy components were shifted to the robot. The human was then only responsible for welding together the components.

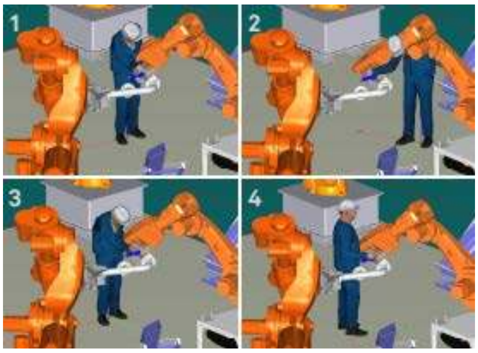


Figure 10: Simulation of HRI for welding operation - Adapted from Busch et al. (2013)

2.8.3 Fully automatic assembly environments

A case study at Casting Technology Farsund (CTF) describes the benefits of implementing fully automatic robotic systems for sand casting of automotive components, Figure 11. In this case, the robot does all the handling of heavy components which included picking and placing them in and out of the machines. The fully automated system saved the operators from heavy lifting of hot components after the casting process. Moreover, the robot also prevents operators from harmful radiations emitted during the inspection of components using X-rays. In this situation, the operators are only doing inspections of the casting process. (Fouché, 2010)

Figure 11: Robots picking and placing automotive components during sand casting – Adapted from Fouché (2010)

In another case study, O'Connor (2008) presented an example of completely robotized welding process at STROS, the manufacturer of hoist machinery used at building sites, Figure 12. The manufacturing of hoist machinery involved a large number of welding operations making it a labor intensive job due to the product complexity. Previously, the welding process required three experienced welders at three workstations. The implementation of robotic solution helped STROS to solve the problems related to recruitment of skilled labor and shop floor space. Moreover, the robot helped to perform the welding process effectively at only one workstation.

Figure 12: Welding of hoist machinery carried out by robot – Adapted from O'Connor (2008)

3 Methods

This Chapter outlines theoretical explanations of the methodology and the tools used, and describe the procedure of how they are applied to meet the aim of this thesis.

3.1 Literature study

According to Bryman and Bell (2007), the importance of the literature study is to gain relevant knowledge of the study area. This is necessary in order to avoid repetition of the same information.

The literature study carried out in this thesis was aimed to gather knowledge about existing theories in the field of study. Additionally, theories related to the methods used were also elaborated. Moreover, the literature study was used to give the project members' insight about assembly solutions in the manufacturing environment. Relevant literature was searched using databases via Chalmers library, ScienceDirect, and Google Scholar. The following keywords were used; Level of automation, Industrial Robot, Industrial Human-Robot Collaboration, and Automation in Assembly Environment.

3.2 Application of the Dynamo++ methodology

Figure 13 illustrates the application of the Dynamo++ in this thesis. It includes several scientific tools that were used in combination with the methodology. As seen, the methodology was adapted to fulfill the goal of this thesis and therefore not all the steps were included. For instance, the third step to do a VSM in the pre-study phase presented in Chapter 2.5.1 was not carried out. This was because the study does not include the mapping of material and information flow of the assembly process. Prior to the on-site measurements at the Tuve plant, the production managers responsible for the selected study areas were informed about the goal of this thesis. Moreover, the project members informed the operators working in the truck chassis assembly line about the study.

In the pre-study phase, the project members did a general walk through of the assembly line to select the study areas which was done in two steps. See Chapter 4.1 for the results of the selection process.

During the measurement phase, the HTA was developed for the tasks carried out by the selected operators. Then the project members photographed and documented tools and equipment used by the operators. Furthermore, an ergonomic study was performed on the selected operators. Finally, the variation in manual work handled by the operators was documented. See Chapters 4.2 to 4.6 for measurement results.

In the analysis phase, workshops were carried out on two different occasions where the first workshop was aimed to combine the tasks obtained in the HTAs developed in the measurement phase and identify suitable ones for improving the LoA, and thereafter design the SoPI matrices. The second workshop discussed improvement suggestions for those tasks within the designed SoPIs. See Chapter 4.7 for the results obtained from the workshops.

At the implementation phase, the project members designed conceptual solutions and concluded with the new HTAs and LoA matrices. See Chapter 4.8 to 4.12 for the designed conceptual solutions.

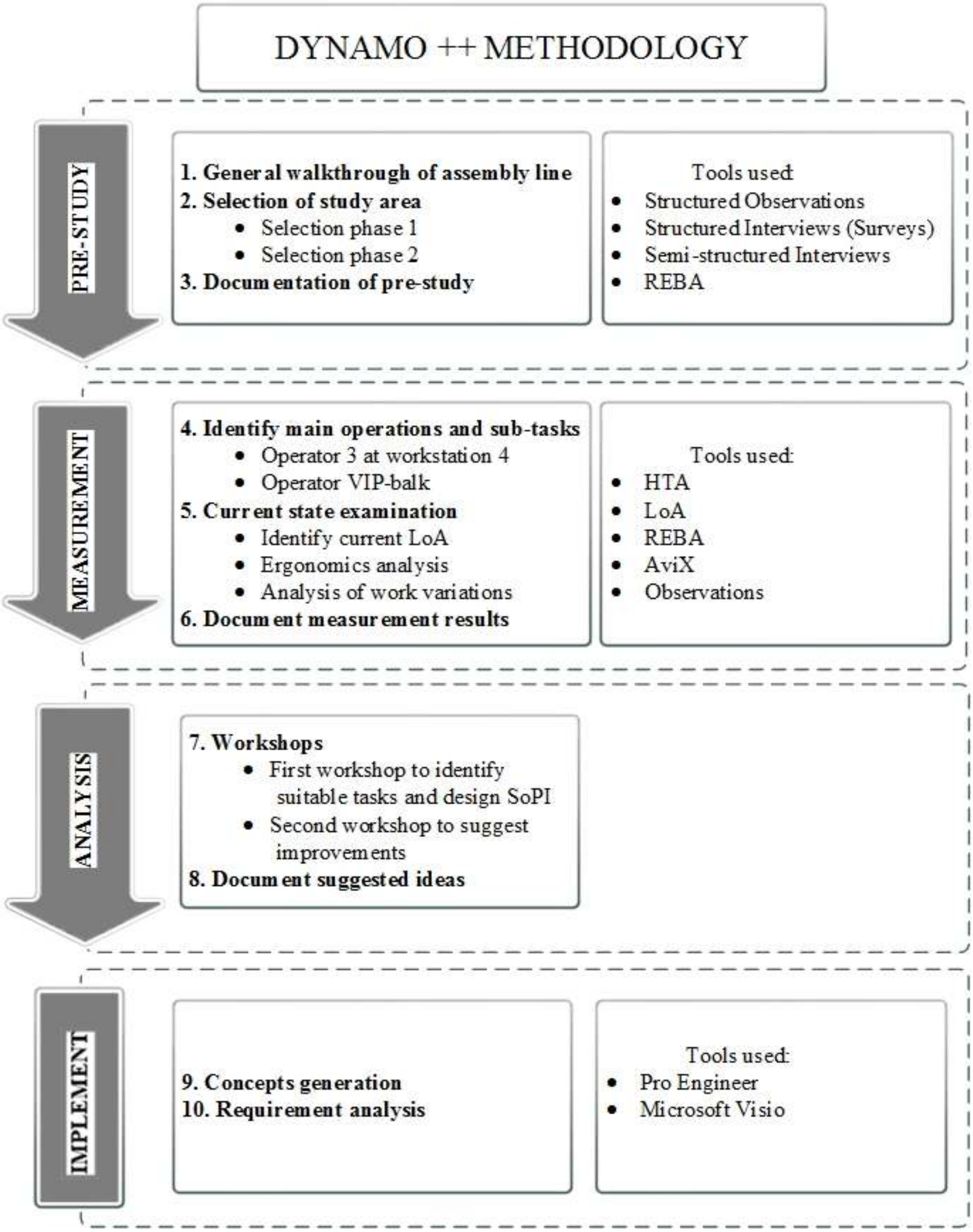


Figure 13: Application of Dynamo++ during this thesis

3.3 Observation study

Observation of behaviors can be carried out using different approaches, among these are, structured observation and non-participant observation (Bryman & Bell, 2007). Structured observation is based on directly observing behaviors using a systematic approach where the observer uses rules for observing and recording the findings. In the non-participant observation, the observer does not participate directly in the activities but only observes.

The procedure for selecting suitable study areas was based on the combination of both the structured and non-participant observations. The project members, the observers, were present in the truck chassis assembly line but did not partake in on-going activities. The non-participant observation was used to select suitable area of the assembly line for the study. Then, the structured observation was used to select suitable part of that area. Finally, it was also used to select suitable workstation in the selected part. Prior to the study, the observers prepared relevant statements, listed in Appendix A, that was used as a base to guide the observations. During the process, behavior of operators, the participants, working in the truck chassis assembly line was observed. This was done using the same statements in order to keep consistency during the study. The observation procedure was carried out in the following order: The study areas were observed twice by two different observers. After each observation the observers' findings were discussed directly before assigning a final score. See Appendix A for the observation results.

3.4 Interviews

During the selection procedure structured interview, a survey, and semi-structured interviews were performed with the four team leaders (TL) responsible for the four parts of the truck chassis assembly line. The TLs were chosen because they had worked for a longer period of time and thereby had better understanding of the process. Moreover, interviewing each operator was difficult due to the time pressure on them.

3.4.1 Structured interview

According to Bryman and Bell (2007), a survey is one kind of research interview carried out during quantitative study where the interviewer enlists identical questions for which every interviewee gives their response. The questions formulated by the interviewer can be closed, closed ended, or fixed choice. The authors further explained that applying this style of interviewing allows easier summarization of the interviewees' answers.

Survey was used twice during the first selection procedure. Firstly, it was used for selecting suitable part of the truck chassis assembly line. Secondly, it was used for selecting suitable workstation in that part. The survey consisted of closed-ended statements which were distributed among the TLs, the interviewees. They were asked to rank each statement on a defined scale, from 1 to 5. The observers also used the same statements for observing the truck chassis assembly line. Then, the recorded responses of the interviewees and the observers were aggregated to choose the suitable part and workstation of the truck chassis assembly line. See Appendix A for the survey results that were obtained.

3.4.2 Semi-structured interview

To get the perspective of the interviewee, a qualitative study in the form of semi-structured or unstructured interviews can be carried out (Bryman & Bell, 2007). In the former strategy, the interviewer enlists the specific topics or questions to be asked using an interview guide. However, during the interview other important aspects may pop-up based on the interviewee's answers. This leads to the situation where the interviewer asks questions other than those already enlisted while keeping the discussion within the scope. In the latter strategy, the interviewer initiates a question or topic and allows the interviewee with an open field to discuss anything about that topic. The interviewer only comes into the discussion when follow-up for any point is needed.

For selecting the suitable part of the truck chassis assembly line, the semi-structured interviews were carried out on the four TLs to gather their views about ongoing activities in the different parts. Prior to the interviews, the project members prepared the interview guide that was used to lead the discussion. During the interviews, the responses of the interviewees were directly written down. Thereafter, those responses were interpreted by looking into the problems faced by the operators in each part. After the interpretation of the interviewees' responses, they were sent back to each of them for their approval. See Appendix B for the interview guide and answers.

3.5 Hierarchical Task Analysis (HTA)

HTA is a method applied by analysts for general examination of tasks, Figure 14 . In the methodology, tasks are explored on hierarchical levels starting with the main goal divided into subtasks, while the sub-tasks in turn are broken down into operations. HTA provides the analyst with good understanding about the situation within which tasks are performed and thereby give possibility to improve them. Each person, the analyst and the task performer, who are part of the process, get an overall view of the tasks and the order in which they are to be performed. The construction of HTA can be done using different techniques; one of them is where the analyst employs observation of the process while the task performer carries out the tasks. Another way is through interviews where the analyst allows the task performer to give step-by-step description of how the task is carried out. Lastly, the analyst can also use work manuals and checklists used by the task performer to construct HTA. (Shepherd, 1998)

The measurement phase of the Dynamo++ methodology was initiated by developing the HTAs of the tasks carried out by the selected operators. The development of the HTAs was based on data gathered from SPRINT and video recordings of tasks performed by the operators. The videos were used to break down the main goal into sub-tasks and further into operations. See Chapter 4.4 and the Appendices J and L for the developed HTAs.

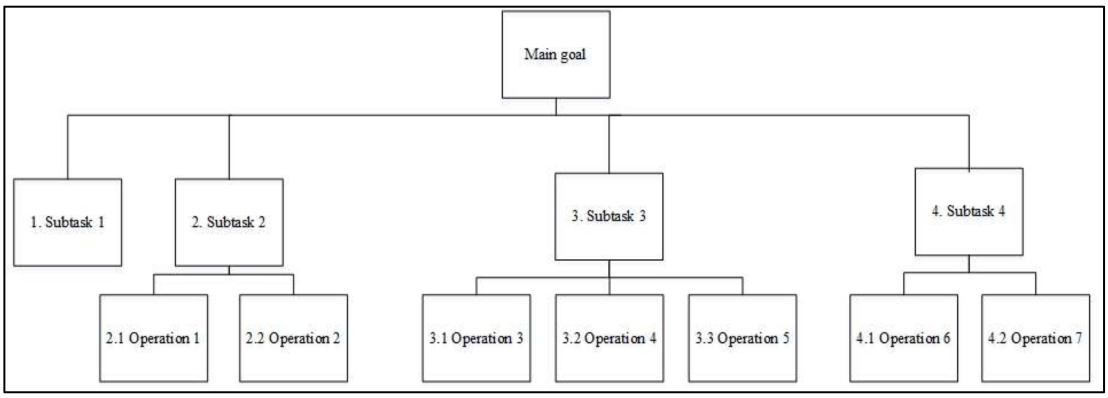


Figure 14: General illustration of HTA – Adapted from Shepherd (1998)

One of the goals of this thesis is also to improve the ergonomic conditions of the selected operators. For this reason, REBA and the Analysis of perceived pain were used to assess the current ergonomic conditions for them. Theoretical background of the tools and their application during this thesis is presented in Chapter 3.6 and 3.7, and the measurement findings in Chapter 4.4, 4.5 and Appendix C.

3.6 Rapid Entire Body Assessment (REBA)

REBA is a posture-based analysis method used to assess the physical ergonomics of workers' entire body postures while performing tasks (Berlin & Adam, 2014). The method was developed by Hignett and McAtammney (2000) where each posture is assessed individually using the REBA assessment worksheet presented in Appendix D. Figure 15 illustrates the REBA scale used to translate REBA scores obtained stating the level of musculo-skeletal disorder (MSD) risk. The method assesses the positions of neck, trunk, legs, arms and wrists as well as considers couplings and grips. Adjustment scores are also added or deducted depending on whether the posture is worsening or made better by different conditions. (Berlin & Adam, 2014)

Score	Level of MSD Risk
1	negligible risk, no action required
2-3	low risk, change may be needed
4-7	medium risk, further investigation, change soon
8-10	high risk, investigate and implement change
11+	very high risk, implement change

Figure 15: REBA scale - Adapted from Hignett and McAtammney (2000)

REBA was used twice during this thesis to assess the operators' postures while performing tasks. Firstly, it was used during the final selection procedure to select the suitable operators for the study, Appendix C. Secondly, it was used during the measurement phase to assess the ergonomic conditions of the selected operators. The REBA assessment was based on recorded videos of the operators while they perform tasks. The assessment was episodic where only the abnormal postures observed in the recorded videos were analyzed. See Chapter 4.4 for REBA analysis of the selected operators.

3.7 Borg Scale

The Borg scale is used to assess physical activities of individuals during work and allows them to indicate the difficulty level of the tasks on a numerical scale, illustrated in Figure 16. The method was developed by the Swedish psychologist Gunnar Borg and originally consisted of fifteen rating points from light to hard physical efforts. Since its origin, it has been modified and now consists of ten rating points. (Kent, 2006)

Figure 16: Borg scale of perceived exertion - Adapted from "AviX Ergo - Is used to improve the ergonomics of the workplace" (2016)

The Analysis of perceived pain for the selected operators was carried out using AviX Ergo ("AviX Ergo - Is used to improve the ergonomics of the workplace", 2016). The assessment in AviX Ergo was based on estimated input data presented in Appendix N. This assessment was also based on the recorded videos of the selected operators. The assessment was episodic where only the abnormal postures observed in the recorded videos were analyzed. The selected postures were shown to the operators who confirmed about the difficulty level while handling the tools and components. The operators allotted the scores themselves according to the Borg scale. See Chapter 4.5 for the results obtained from this analysis.

3.8 Workshops

Workshops were held at GTO Tuve plant on two different occasions where the first workshop was aimed to combine the tasks obtained in the HTAs that were developed during the measurement phase and to identify suitable ones for improving the LoA. Moreover, this workshop was aimed to decide the relative minimum and maximum LoA for those tasks and to design the SoPIs for the selected operators. The second workshop was aimed to generate improvement suggestions within the designed SoPIs. See Chapter 4.7 for the results of the workshops.

At the first workshop, only stakeholders from GTO and Chalmers together with the project members were present. This workshop initiated by combining the tasks obtained in the current state HTAs and then identifying suitable ones for improving the LoA. Thereafter, new the HTAs were constructed where the main goals were broken down into functional level and further into sub-tasks. After the HTAs were constructed, the current LoA were decided for each task. This was followed by designing the SoPI matrices for those tasks.

The second workshop was aimed to discuss possible improvement suggestions for the tasks selected in the first workshop. The main focus of this workshop was to generate improvement ideas keeping in mind the TfCs. The workshop included operators from workstation 4 and the VIP-cross member subassembly line. Additionally, production managers responsible for the study areas were also present together with stakeholders from GTO and Chalmers. Finally, some engineers from other departments within GTO also participated.

Prior to the workshop, the project members together with supervisor from Chalmers discussed and listed limitations that needed to be considered while discussing improvements. The listed points included;

- Need for flexibility: If the proposed solution is flexible enough to handle the large product variation
- Speed and weight: If the suggested solution is capable to perform the tasks within the cycle time and also able to handle heavy components
- Competence or experience level: If the company has the level of knowledge required to use the proposed solution
- Information system: If the company's information system can be integrated with the solution
- Physical space: If there is enough floor space for implementation of the suggested solution in the assembly environment
- Safety or regulations: Refers to the speed of the robotic solution in case of human-robot collaboration to avoid injury to operators. Moreover, it refers to overall safety of the operators if the solution is implemented in the main line.
- Parallel working of resources. This limitation refers to whether tools and machines could be operated in parallel.

The workshop initiated with project members presenting the measurement findings about the current system. It included explanation of the goal of this thesis and description of the Dynamo++ methodology along with the LoA concept. Thereafter, the project members showed the participants the HTAs and LoA matrices together with REBA scores of the operators' postures. To give the participants more insight, the project members showed videos of the operators while performing tasks.

Thereafter, the workshop moved over to a brainstorming and an idea generation session. This was done by dividing the participants into two groups and each group discussed improvements of different tasks in the HTAs. Each group was responsible for writing down their ideas considering the limitations listed above.

All necessary information that the groups needed to lead the discussion were available. This included the HTAs of the operators, corresponding LoA matrices, list of components and their weights and the LoA scales. The workshop concluded with the list of several improvement suggestions.

3.9 Reliability and Validity

According to Bryman and Bell (2007), the terms reliability and validity are criteria used to evaluate the findings in a study. Reliability refers to consistency of obtained measures, that is, whether a third party can repeat the procedure of a study and arrive at the same result. Validity is a way to ensure that measures obtained shows what is actually supposed to be measured.

The findings in this thesis were validated on several occasions where the project members consulted the thesis examiner and supervisor from Chalmers, and the engineers at GTO to gather their views.

To increase the reliability of the observational study, an approach of *inter-observer consistency* was conducted (Bryman & Bell, 2007). In this approach, the project members separately observed the operators in the truck chassis assembly line and thereafter discussed their findings before agreeing on common scores. To increase the validity of the observation, the statements used were developed by the project members in the form of *Observational schedule* (Bryman & Bell, 2007) and the decision was made to follow the schedule in the same order.

During the survey, project members ensured that TL responses were not influenced by each other. This was done by conducting the surveys individually without allowing the TL to interact. The validity of the scores obtained from the survey was ensured by comparing them with the scores set by project members' direct observations of the same statements. The final scores were then set by taking the mean of the survey and the observation scores in order to reduce biases.

After the interviews were conducted, they were analyzed immediately. This was done to ensure correct interpretation and thereby increasing the credibility. To further increase the credibility of the interview, the project members utilized the *respondent validation* technique (Bryman & Bell, 2007) where interpretation of the interview answers was send back to each interviewee for their approval. Reliability of the interviews was ensured by allowing one of the project members to conduct all the interviews. To respect the interviewees' privacy their names were not mentioned in this report, instead they were referred to as TL.

Before recording the videos that were used for the REBA analysis and the Analysis of perceived pain, the operators were asked to perform the tasks following standardized procedure. This was done to avoid operators' own way of performing the task which could lead to unrealistic analysis.

The Analysis of perceived pain using AviX Ergo was validated where the operators themselves were allowed to assign the scores in the manikins while assessing the difficulty level for handling the tools and components. They did that by looking at the recorded videos of themselves while performing the tasks.

4 Empirical findings and Results

This Chapter documents the results obtained after using the method and tools described in Chapter 3.

4.1 Selection of the study area

The initial phase of this thesis was to select appropriate study areas for the application of the Dynamo++ methodology. This was carried out in two steps explained below.

4.1.1 Selection step 1

This step was aimed to identify suitable workstation(s) of the main assembly line for the study. Figure 17 illustrates the result after the findings were presented at a milestone meeting with stakeholders from GTO and Chalmers. See Appendix A for description of this step which was carried out in the following order;

- After the general walk through of the assembly line, the Base module area was selected for the study because the stakeholders' concerns and the project members' observations showed manual handling of heavy tools and components by the operators. Moreover, the observations showed high variation in manual work for the different trucks chassis assembled there.
- Thereafter, part 2 of the Base module was chosen because it obtained the highest score based on the project members structured observations and the TLs survey results. Moreover, the interview answers from the TL concluded that the operators here are handling heavy tools and components, which increases the risk of the operators getting injured.
- Finally, workstation 4 of part 2 was selected for further investigation in order to identify a suitable operator for the study. The selection was made due to the stakeholder's concerns about the riveting task happening there.
- Additionally, the decision was taken to examine the three sub-assembly lines associated with workstation 3 and select one of them to set an appropriate scope for the thesis.

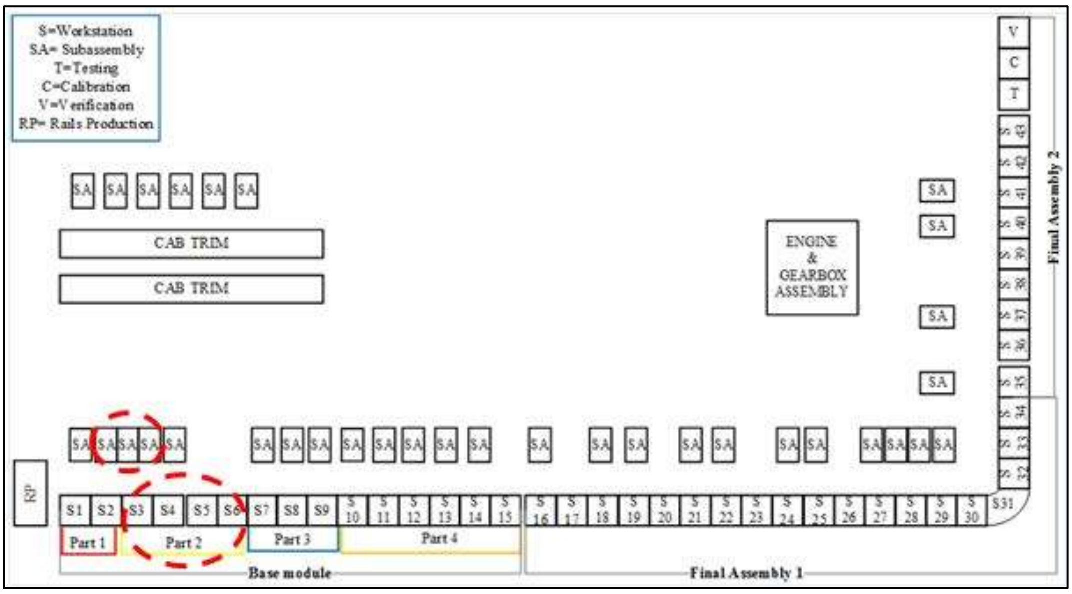


Figure 17: The final result of selection step 1

4.1.2 Selection step 2

This selection procedure was aimed to select an operator doing riveting at workstation 4 and also choose one of the subassembly lines associated with workstation 3. The selection procedure was based on the TfC presented in Chapter 2.6.

Figure 18 illustrates the result of this step and Appendix C contains description of the selection procedure. The selection was carried out in the following order;

- The amount of manual work carried out by the operators at workstation 4 and the subassembly lines was listed using SPRINT.
- The operators were compared based on the amount of manual work which showed that operator 1 and 2 performed similar tasks and therefore were considered as single operator. Operators 3 and 4 were doing identical riveting tasks but differed while mounting the V-STAY, see Appendix I for the glossary. Operator 3 is responsible for inserting the V-STAY while operator 4 fastened the screws on it. The project members' observations showed that inserting the V-STAY was more critical than screwing it and therefore operator 3 was chosen. To proceed further, operator 1 and 3 were chosen.
- Thereafter, an ergonomic analysis of operator 1 and 3 and the operators in the subassembly lines were carried out by using REBA.
- The results were presented to the stakeholders and the decision was made to choose operator 3 at workstation 4 for the study. This was because operator 3 performed the highest amount of critical tasks which include riveting, vertical screwing and mounting the V-STAY. Additionally, high REBA scores were obtained for operator 3 which indicated that change is needed due to high ergonomic risks.
- In addition, the operator at the VIP-cross member subassembly line was selected for the study. This subassembly line was chosen due to the high REBA scores and to have a balanced workload because the study will consider the large variation handled by operator 3. At this subassembly line, only the standardized product is assembled.

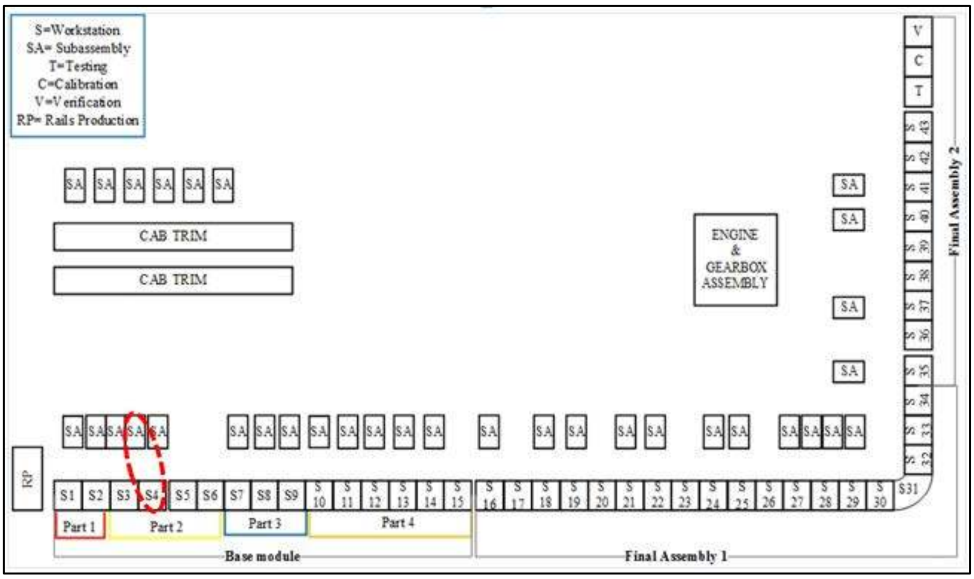


Figure 18: The final result of selection step 2

4.1.3 The selected operators

Figure 19 shows workstation 4 where operator 3 is positioned at the rear left side. At this position, the operator has the responsibility of performing various tasks on the rear part of the chassis. Table 2 lists the tasks performed by this operator. The major responsibility of this operator is to fasten the rivets on the Reaction rod on which the rear axle suspensions are mounted further in the assembly line. The design of the Reaction rod is dependent on the rear axle suspension variant which decides the amount of riveting tasks that this operator has to carry out. Installation of the rear axle suspensions is the source of variation in the amount of manual work handled by the operator and is explained further in Chapter 4.2. See Appendix I for the Glossary.

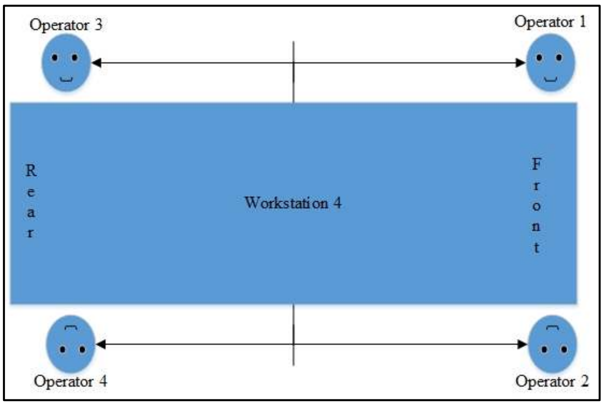


Figure 19: Workstation 4 of the Base module

Table 2: Manual work handled by operator 3

Manual work
Riveting Reaction rod
Riveting cross members
Vertical screwing operations
Inserting V-STAY in chassis
Inserting screws in V-STAY

Figure 20 shows the location of the VIP-cross member subassembly line delivering the assembled product at workstation 3 of the Base module. Table 3 lists the tasks performed by the operator at the VIP-cross member subassembly line. The VIP-cross member is mounted on the chassis to give strength to the front part and secure side way movement of the axle. The components used by the operator for assembling the VIP-cross member are placed in material pallets situated near the workstation. This operator follows the same assembly routine as the product is standardized.

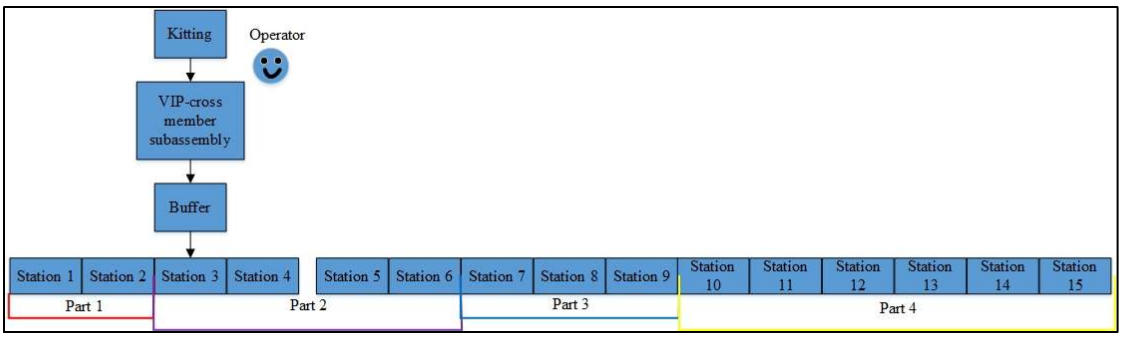


Figure 20: The VIP-cross member subassembly line and workstations in the Base module area

Table 3: Manual work handled by operator at VIP-cross member subassembly line

Manual work
Placing components on fixture
Inserting rivets
Mounting/Un-mounting screws
Riveting VIP-cross member
Transfer VIP-cross member to carrier

4.2 Variations in manual work

This Chapter aims to highlight the variation in manual work handled by operator 3 while working on the Reaction rod. As mentioned earlier, the design of the Reaction rod varies depending on the rear axle suspension variant that is installed in Final assembly 1 of the assembly line. Changes in the design of the Reaction rod mean that the operator has to fasten a different amount of rivets. This variation is important to consider while discussing possibilities for improving the LoA later in the analysis phase. Figure 21 illustrates the types of rear axle suspensions. There are two types of rear axle suspension, leaf and air (GR, G2). Leaf suspensions can be either parabolic (L90, AR, BR, TR1) or conventional (TR1, TR2).

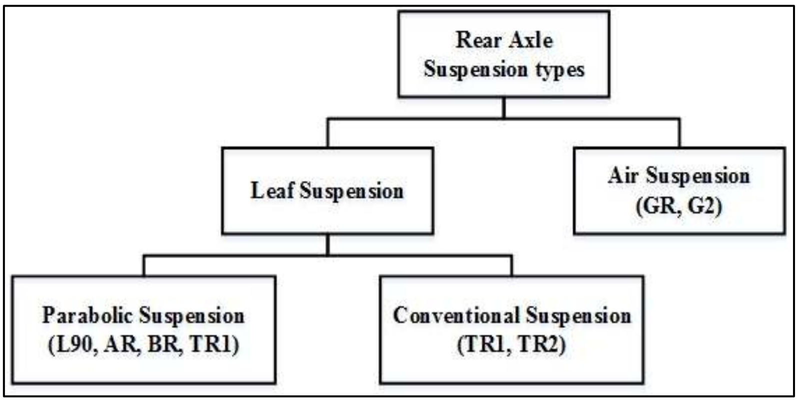


Figure 21: Rear axle suspension types

Figure 22 illustrates percentages of fifteen rear axle suspension variants installed for each work day during week 7 and week 8. According to the collected data from EDB, a majority of the rear axle suspension variants installed were the air type. See Appendix E for data used.

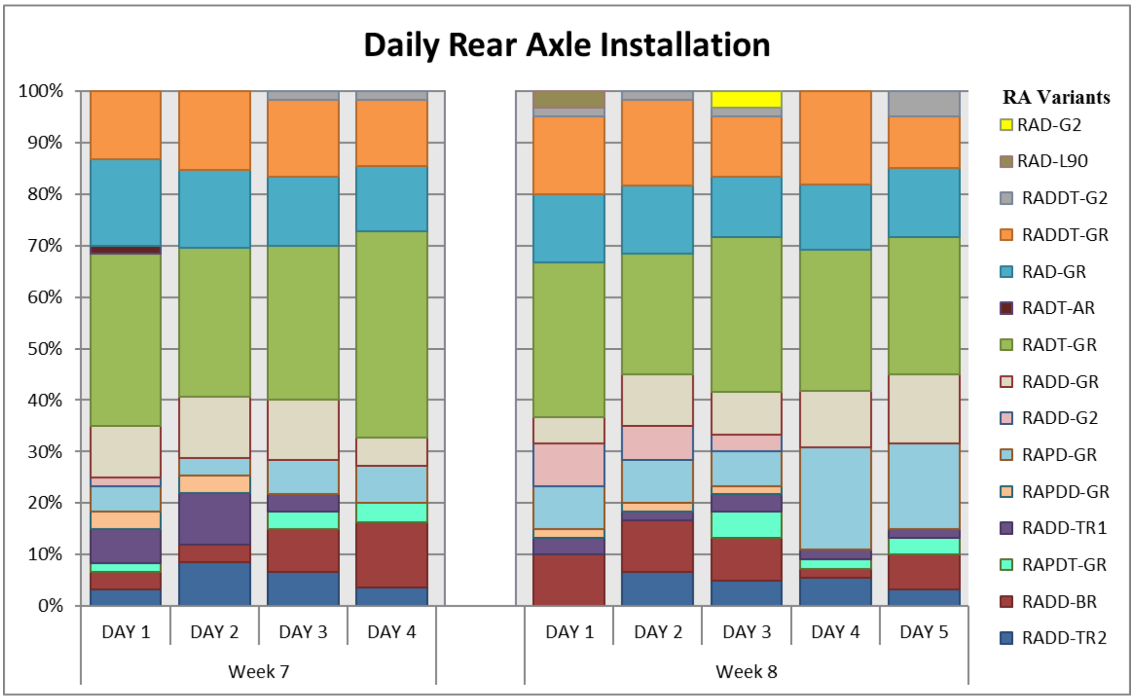


Figure 22: Daily rear axle suspension Installation for week 7 and week 8

Figure 23 below exemplifies the order in which the rear axle suspension variants were installed on the first working day of week 7 starting with RADDT-GR. The total amount of trucks assembled on that day was sixty. It can be seen that the probability of installing the same suspension variant more than twice is rare which means that the operator has to keep track of the work routine for the different chassis coming at the workstation. See Appendix F for the data used which was collected from EDB.

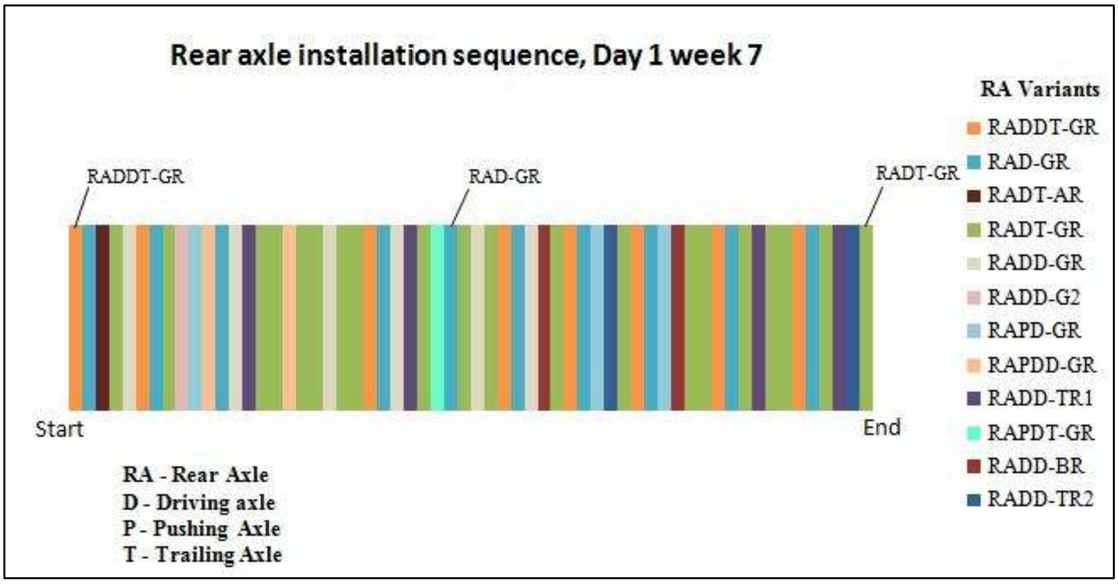


Figure 23: Rear axle installation sequence

Figure 24 illustrates the average workload for operator 3 while performing tasks on the reaction rod. The graph was constructed based on the two weeks data gathered from EDB. The highest average workload was for the variant RADD-TR1 for which the operator performs the most manual work and it was therefore chosen for the study in the measurement phase. The amount of manual work carried out on this variant includes the work for all the other variants. See Appendix G for the data table.

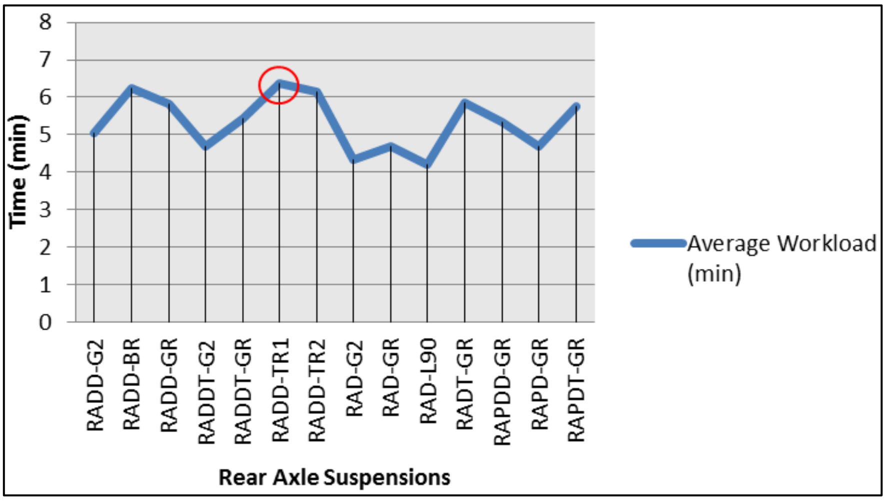


Figure 24: Average workload for installing rear axle suspensions

Figure 25 illustrates variation in wheelbase length for week 7 and 8. The wheelbase length is the length between the front and the rear axles of the chassis which varies from minimum 3000 millimeters to maximum 6400 millimeters. According to the figure, different rear axle suspension variants can be mounted on different wheelbase lengths. Depending on the position of the tools and the wheelbase length of the chassis coming at the workstation, operator 3 has to cover different distances to perform the assigned tasks. For example, for the truck with the shortest wheelbase length of 3000 millimeters, the operator travels the longest distance with the tool to reach the position of the tasks and vice versa. See Appendix H for the data collected from EDB.

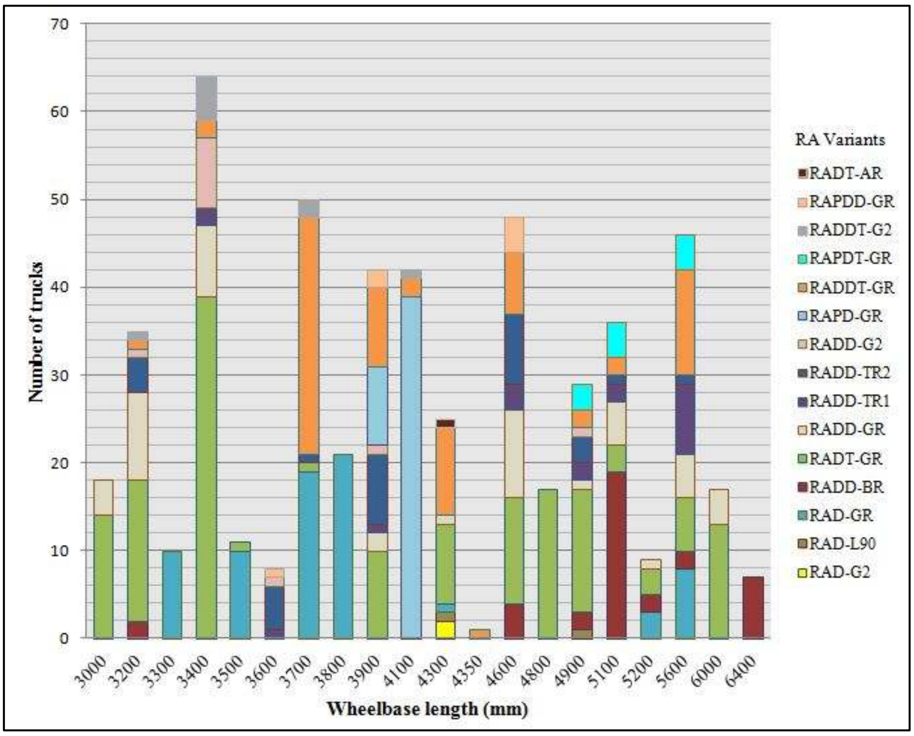


Figure 25: Variation in Wheelbase length

4.3 Current state analysis

An examination of the current LoA for the selected operators was carried out. The tools and work instructions used by the operators were photographed and documented, and thereafter the appropriate LoA was assessed using the LoA scales and LoA matrix presented in Chapter 2.4.

4.3.1 Operator 3 at workstation 4

Figure 26 shows tools used by this operator and Table 4 lists the components, fixtures, tools and information. The rivet tool, Figure 26(a), is used to fasten all rivets and weighs approximately 150 kilograms. The fixture, Figure 26(b), for holding the rivet tool is fixed on the floor and helps to keep the tool in place so that it does not hinder the operator while working. The lifting tool for the V-STAY, Figure 26(e), is used to pick and carry the V-STAY into the chassis and is equipped with a handle to enable orientation of the component before it is placed. A fixture, Figure 26(d), is used to batch the V-STAY for only two trucks at a time. The automatic screwdriver, Figure 26(c), for tightening the screws is hanged and coupled with a spanner to hold the nut during screwing. Figure 26(f) and Figure 26(g) illustrates another automatic screwdriver and spanner also used by the operator.

Only paper work instructions are present at the workstation which is similar to the other workstations in the Base module area, beside associated subassemblies where a pick-to-light solution is used. The work instructions do not give pictorial illustration of the tasks, but only list the amount of components that are to be assembled. Finding the exact positions for where the components should be mounted is totally based on the operator's experiences. See Appendix I for the Glossary.

Figure 26: (a) (b) (c) (d) (e) (f) (g)

Table 4: Tools and work instructions used by Operator 3

Components	**Fixtures**	**Tools (LoA_{mech})**	**Information (LoA_{info})**
• V-STAY • Screws M20*110 • Screws M16*70	• V-STAY Carrier (d) • Rivet tool fixture (b)	• V-STAY lifting tool (e) • Rivet tool (a) • Automatic screwdrivers (c) (f) • Spanner (g)	• Paper work instruction • Operators experiences

4.3.2 Operator at VIP-cross member subassembly line

Figure 27 shows tools used by this operator and Table 5 lists the components, fixtures, tools, and information. The rivet tool, Figure 27(d), weighs 150 kilograms and is similar to the one used by operator 3 at workstation 4. The components are placed on a static fixture, Figure 27(a), where they are assembled. After the VIP-cross member is assembled it is transported to the carrier, Figure 27(c), with a lifting tool, Figure 27(b). The lifting tool is equipped with a magnetic head that is positioned on the VIP-cross member before it is lifted off the fixture. For placing the VIP-cross member onto the carrier an instruction, Figure 27(e), is available to assure that its orientation is correct. This is to avoid difficulties when mounting it onto the chassis in the main line. After five VIP-cross members are assembled the carrier is transported to workstation 3 in the main line.

The assembly work in this subassembly line relies only on the operator's experience. The reason for this could be that the product is standardized thereby similar assembly procedure is used all the time.

Figure 27: (a) (b) (c) (d) (e)

Table 5: Tools and work instructions used by Operator at VIP-cross member subassembly line

Components	Materials	Fixtures	Tools (LoA_{mech})	Information (LoA_{info})
• Anchorage VIP • Cross member • Anchorage cross	• Rivets • Nut-bolt • Materials pallet	• Static fixture (a) • Fixture for material pallet • Carrier for VIP-cross member (c) • Fixture for holding rivet tool	• Lifting tool (b) • Rivet tool (d) • Hands	• Operator experience • Instructions for placing VIP-cross member (e)

4.4 HTA and current state ergonomic analysis

This Chapter presents the HTA constructed for the selected operators and also includes an ergonomic analysis carried out while they perform the tasks. The REBA scores obtained for both operators shown in Figure 28 and Figure 29 are high according to the REBA scale presented in Figure 15 which indicates that they face high risks for injuries and that change is needed.

Figure 28 presents the HTA describing the main goal and the sub-tasks for operator 3. The operator has to handle variation while fastening the rivets and therefore it has been indicated in the HTA to repeat sub-tasks 2 and 3 until all rivets are fastened. Figure 28 also shows abnormal postures and their corresponding REBA scores described in Table 6. The color markings around each score are according to the REBA scale. See Appendix J for the complete HTA and Appendix K for the REBA analysis.

Figure 28: HTA showing the main goal, sub-tasks and REBA scores for Operator 3 at workstation 4

Table 6: Tasks and description of postures

Tasks	**Description of postures**
Fastening rivets	The operator has to bend and stretch his neck in order to accurately position the rivet tool on the rivets.
Handling rivet tool	Handling the rivet tool requires the operator to stand in abnormal postures which is due to the size and weight of the tool.
Mounting V-STAY	The task requires bending and twisting of back and neck in order to accurately perform it. Additionally, there is also a risk that the operator's fingers get pinched which is due to the narrow space in the chassis.
Reaching screwing tool	The automatic screwdriver is hanging which requires the operator to stretch far to reach it.
Vertical screwing	This task requires bending and twisting of the back and neck in order to accurately perform it.

Figure 29 presents the HTA describing the main goal and the sub-tasks for the operator at the VIP-cross member subassembly line. The operator assembling the VIP-cross member has to follow the same assembly routine because the product is standardized. Figure 29 also shows abnormal postures and their corresponding REBA scores described in Table 7. See Appendix L for the complete HTA and Appendix M for the REBA analysis.

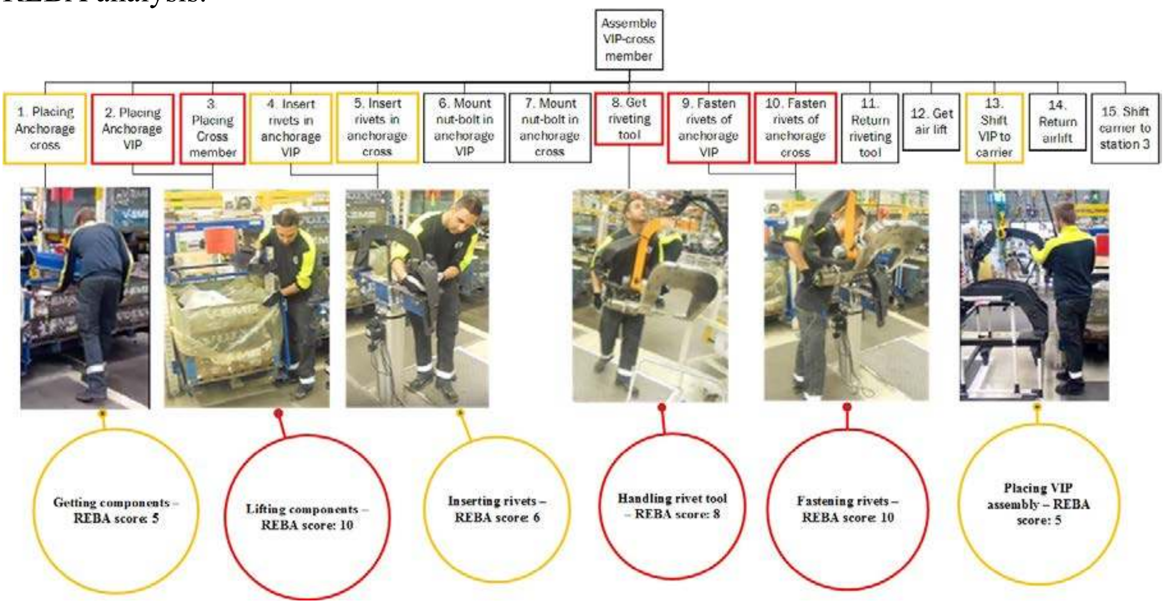


Figure 29: HTA showing the main goal, sub-tasks and REBA scores for the operator at VIP balk subassembly line

Table 7: Tasks and description of postures

Task	Description of posture
Getting components	The operator has to bend and stretch forward to grab and pick the component. The material pallets are placed in a fixture which requires the operator to first pull out the pallet before grabbing the component.
Lifting components	The operator has to bend and twist his neck while lifting the component with one hand and simultaneously push in the pallet with the other hand.
Inserting rivets	This task requires the operator to bend his back in order to place the rivets correctly because the fixture is not adjustable.
Handling rivet tool	The rivet tool is similar to that of operator 3 and requires the operator to stand in abnormal postures while grabbing it.
Fastening rivets	The operator's neck is bent and shoulder is raised in order to properly see the position of the rivets and perform the task.
Placing VIP assembly	The operator uses one hand to grab the VIP-cross member and the other hand to control the lifting tool.

4.5 Analysis of perceived pain

The analysis of perceived pain for the selected operators was carried out. The aim was to gather the operators' view about the difficulty level while handling the tools and components. See Appendix N for the information used for the analysis in AviX Ergo. The information was gathered by observing SPRINT. The scores in the manikins shown in Figure 31 and Figure 33 were set by the operators while looking at the recorded videos of them performing the tasks. As seen, the scores set by the operators are high according to the Borg scale illustrated in Figure 16 which shows concerns that needs to be addressed.

Table 8 lists the tasks performed by operator 3 at workstation 4 and gives description of the problems associated with them. Figure 30 shows the operator's postures while performing these tasks and the manikins showing the level of perceived pain in the different body parts, Figure 31.

Table 8: Tasks and description of associated problems

Fig. Ref.	Tasks	Problems
31 (a)	Horizontal riveting	"I have to apply force using hands to position the tool on the rivets and I have to twist my elbow"
31 (b)	Walking while holding tool	"I have to hold the tool and walk with it which require me raising my shoulders high and apply force in order to control the tool"
31 (c)	Vertical screwing	"Due to the obstacle in the way I have to raise my shoulder high to position the tool on the screws and apply force to carry out the task and I have to bend my neck to see them properly"
31 (d)	Carrying V-STAY	"I have to bend my back and neck to pick the component before carrying it to chassis"
31 (e)	Inserting V-STAY and screws	"To insert the components I have to bend my back and twist my arms to reach and bent and twist my neck to see the position"

Figure 30: (a) (b) (c) (d) (e)

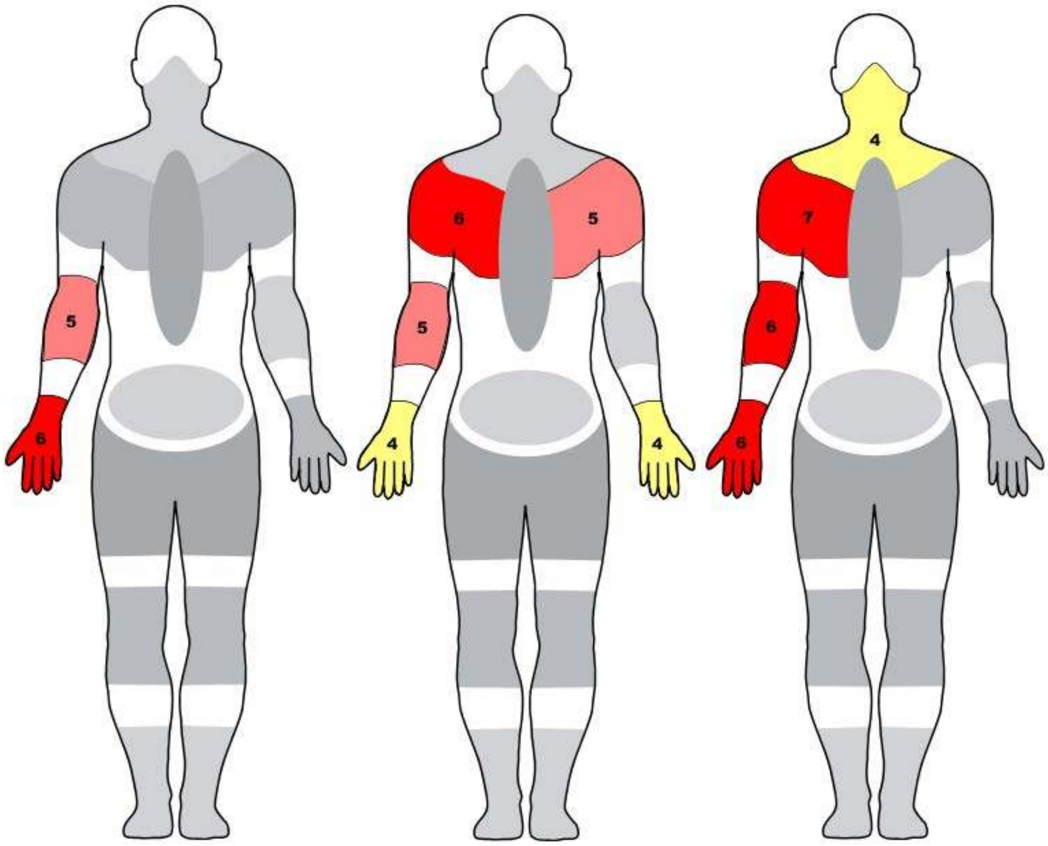
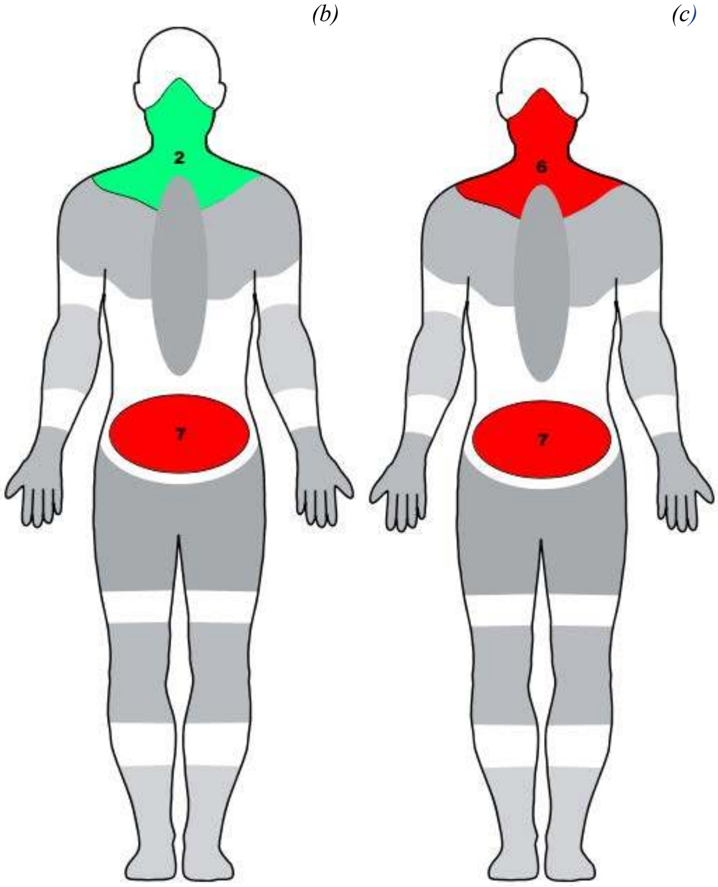


Figure 31: *(a)* *(b)* *(c)*



(d) *(e)*

Table 9 lists the tasks performed by the operator at the VIP-cross member sub-assembly line and gives description of the problems associated with them. Figure 32 shows the operator's postures while performing these tasks and the manikins showing the level of perceived pain in the different body parts, Figure 33.

Table 9: Tasks and description of associated problems

Fig. Ref.	**Tasks**	**Problems**
33 (a)	Holding components and pushing in the pallet	"The components are heavy and I have to hold them in one hand and simultaneously push in the material pallet with the other"
33 (b)	Getting components	"I have to bend my back and stretch my arms to reach and pick the components"
33 (c)	Screwing with fingers	"I have to use my fingers to fasten and unfasten the screws"
33 (d)	Grabbing rivet tool	"The tool is heavy and I apply force with my hands to grab it and walk while holding it"
33 (e)	Horizontal riveting	"In order to position the tool on the rivets I have to stretch my neck to see the exact position and I also have to bend my elbow to operate the tool"

Figure 32: (a) (b) (c) (d) (e)

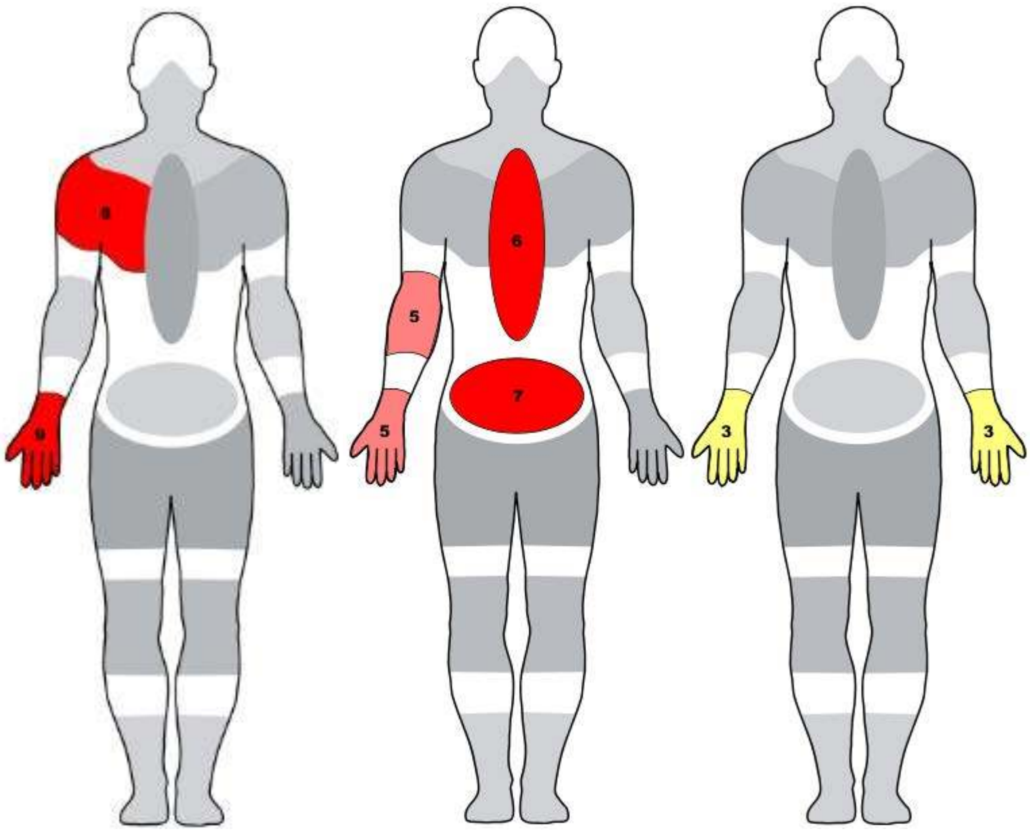
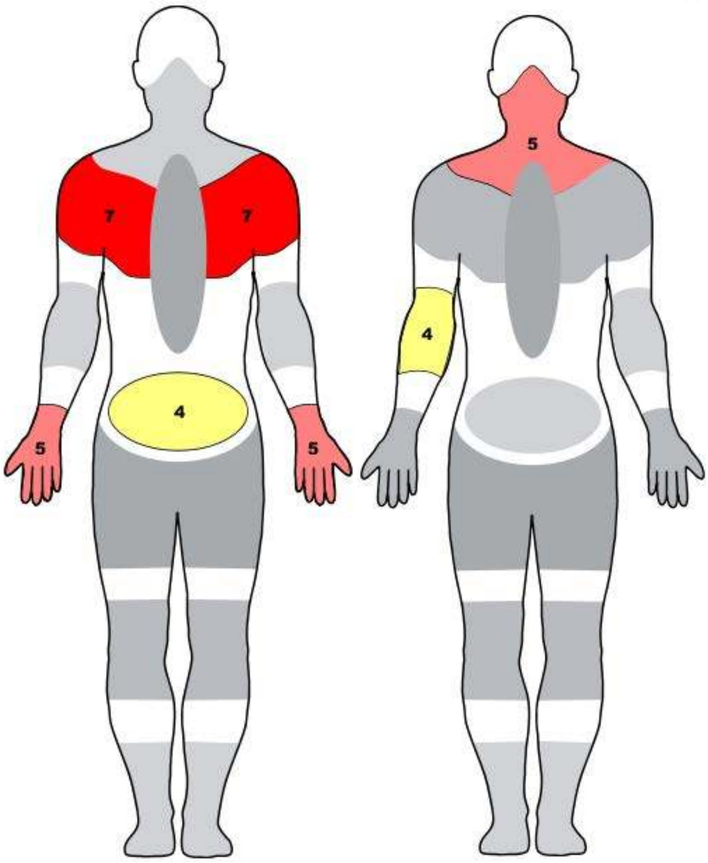


Figure 33: (a) (b) (c)



(d) (e)

4.6 The current LoA

Figure 34 and Figure 35 illustrates the current LoA matrices for operator 3 and the operator at the VIP-cross member subassembly line. The value in each of the boxes is the total amount of tasks with the same LoA. In both matrices, it can be seen that all the tasks in the current system are located in the human assembling and monitoring area, meaning that the operators are performing the tasks manually using different tools.

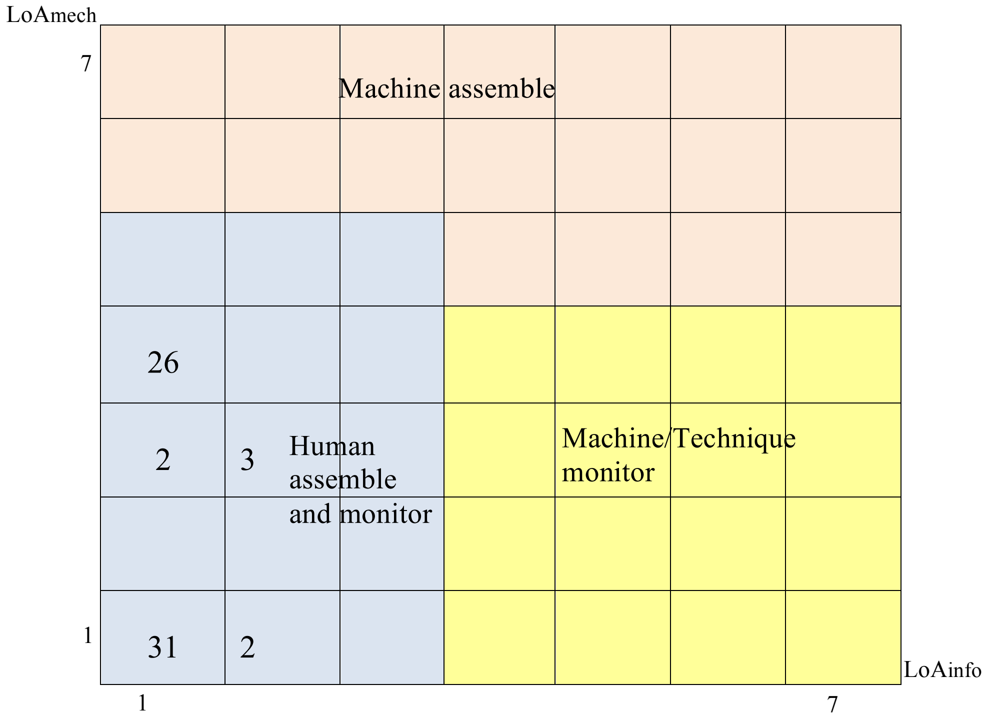


Figure 34: LoA matrix showing the current LoA for Operator 3

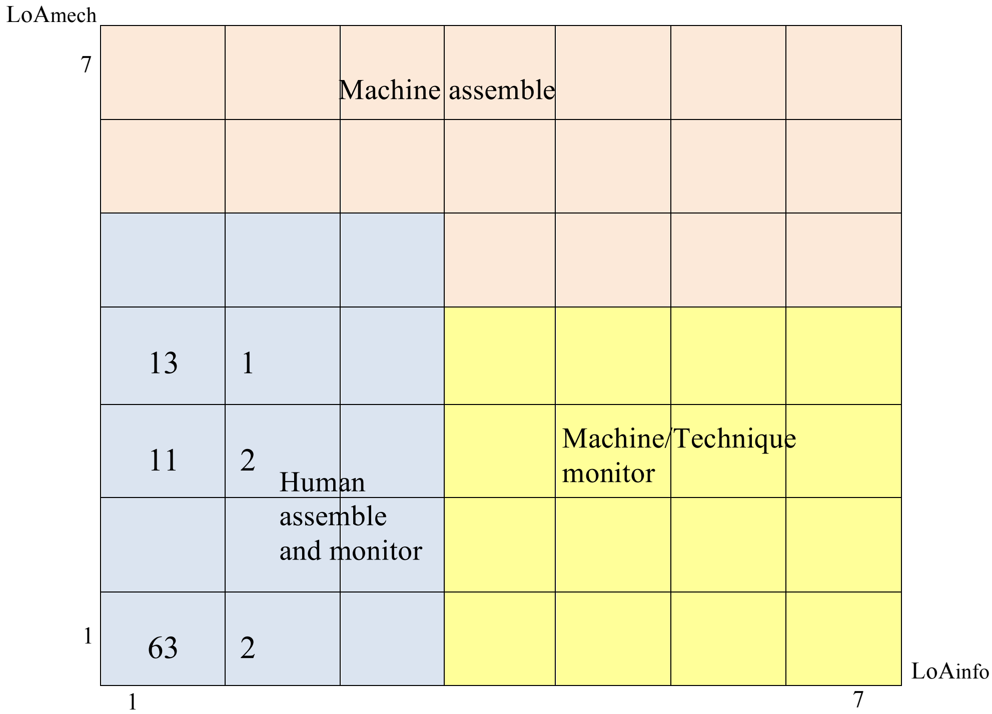


Figure 35: LoA matrix showing the current LoA for the operator at the VIP-cross member

Table 10 and Table 11 exemplify the LoA tables showing detailed LoA for some tasks carried out by both operators. The current LoA for each sub-task and operation is represented by x. See Appendix O and Appendix P for the complete LoA tables.

Table 10: Example of the LoA table for operator 3

	Operations			Operations	
LoAmech	1.1	1.2	**LoAinfo**	1.1	1.2
7			7		
6			6		
5			5		
4			4		
3			3		
2			2		
1	x	x	1	x	x

Table 11: Example of the LoA table for the operator at the VIP-cross member subassembly

	Operations							Operations					
LoAmech	1.1	1.2	1.3	1.4	1.5	1.6	**LoAinfo**	1.1	1.2	1.3	1.4	1.5	1.6
7							7						
6							6						
5							5						
4							4						
3		x		x			3						
2							2						
1	x		x		x	x	1	x	x	x	x	x	x

4.7 Workshop

The workshops were used to decide the relative minimum and maximum LoA as well as generate improvement suggestions to improve the LoA. They were carried out on two different occasions.

4.7.1 The first workshop

As presented in Figure 34 and Figure 35, the total amount of tasks obtained from the HTAs for operator 3 and the operator at the VIP-cross member subassembly were sixty-four and ninety-two respectively. Increasing the LoA for all of these tasks would be time consuming and the project time is limited. Therefore, this workshop was aimed to combine those tasks and to select suitable ones form improving the LoA. These tasks will be presented at the second workshop for the discussions about increasing the LoA.

Figure 36 and Figure 37 illustrate new HTAs constructed for the selected operators. In these HTAs, the main goals are broken down into functional levels and further into sub-tasks. The tasks on functional level will be used to discuss possibilities for improving the LoA outside the current system. The sub-tasks will be used to discuss the LoA improvements within the existing system. The sub-tasks were selected based on REBA scores presented in Chapter 4.4.

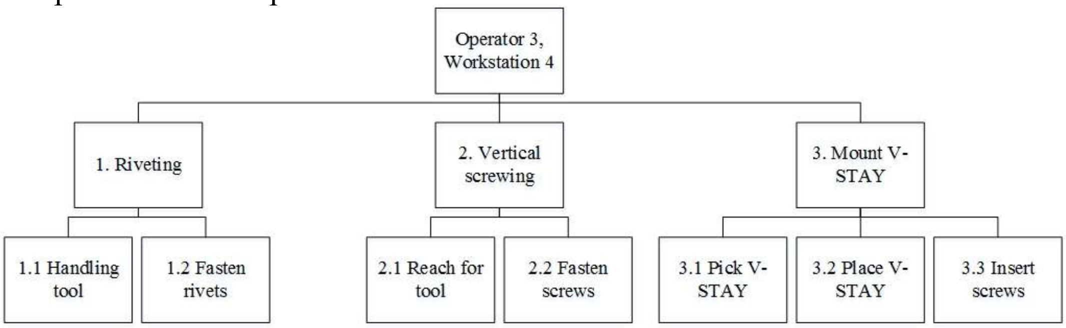


Figure 36: The new HTA showing the tasks for improving the LoA for operator 3

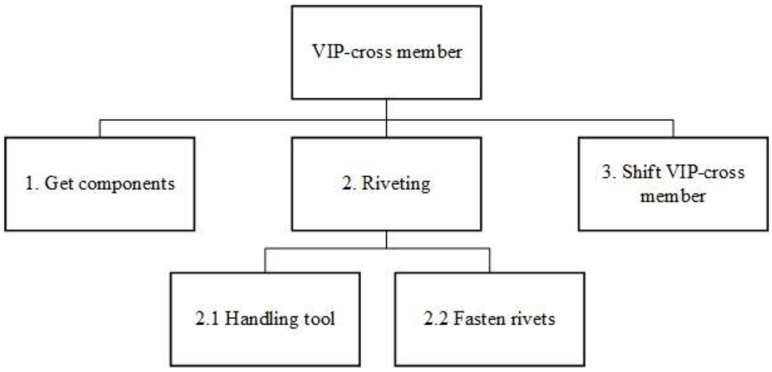


Figure 37: The new HTA showing the tasks for improving the LoA for the operator at the VIP-cross member subassembly line

Figure 38 and Figure 39 illustrate the new LoA matrices for the selected operators. The matrices show the current LoA of the tasks presented in the new HTAs above. As seen all the tasks are carried out manually and are located in the human assembling and monitoring area of the matrices.

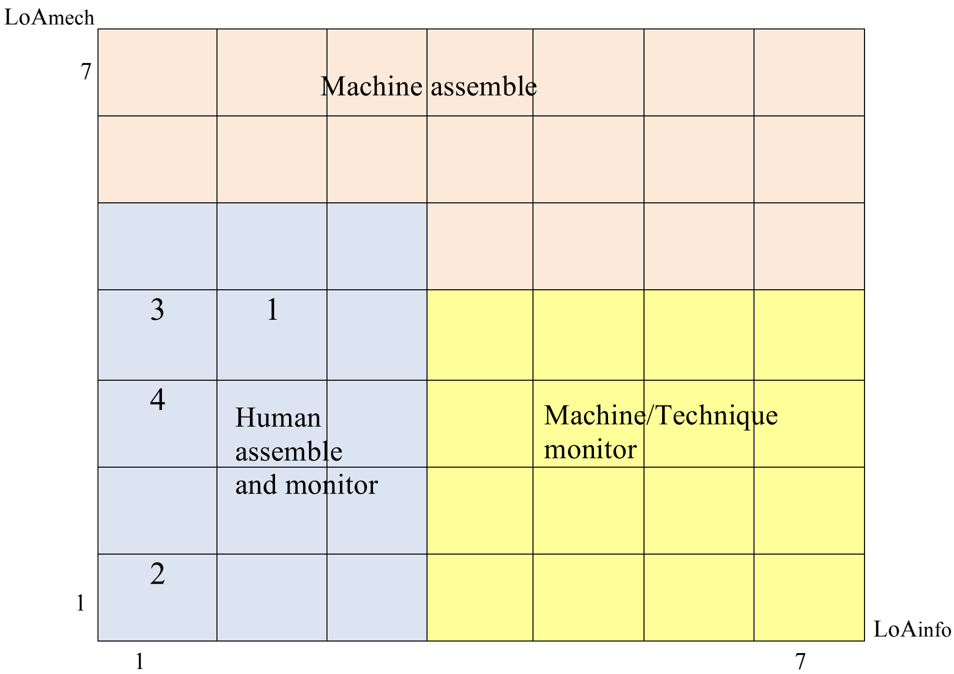


Figure 38: The new LoA matrix showing the current LoA for operator 3. The value in each of the boxes is the total amount of tasks with the same LoA

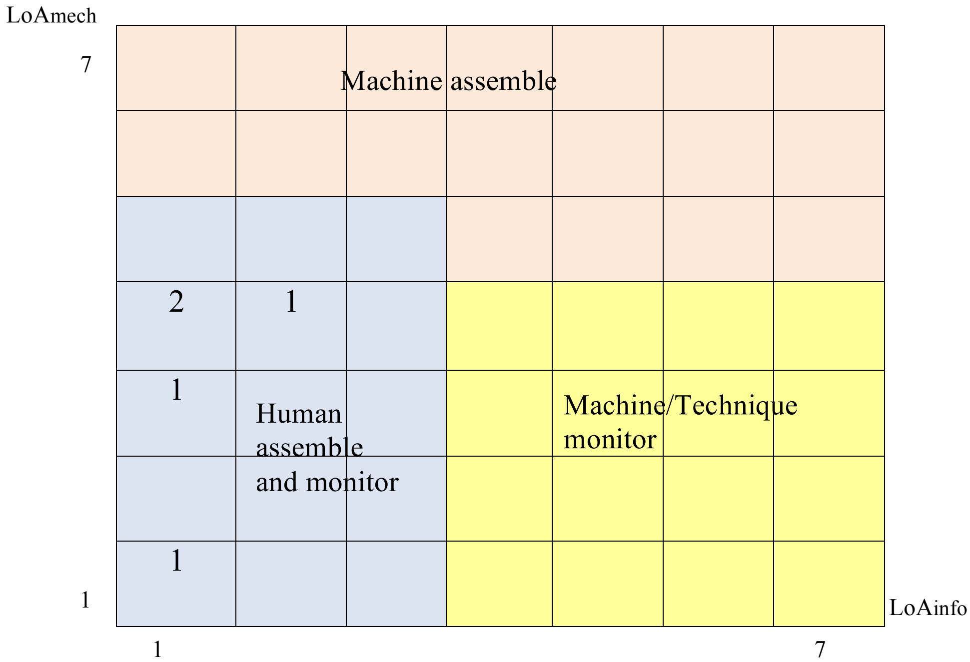


Figure 39: The LoA matrix showing the current LoA for the operator at the VIP-cross member subassembly line. The value in each of the boxes is the total amount of tasks with the same LoA

4.7.2 The SoPI matrices

Based on the TfCs which are, to reduce the amount of manual work and improve the ergonomics, the minimum and maximum LoA on the LoA_{mech} were decided from level 5 to 7. The TfCs were mainly related to improving the physical condition of the operators and therefore the LoA_{info} was kept open from level 1 to 7. The decided minimum and maximum LoA are based on the assumptions of the participants at the first workshop.

Figure 40 and Figure 41 present the SoPI matrices for the tasks performed by both operators. In order to reduce the amount of manual work and improve the ergonomics for the operators, the discussions about improvement suggestions are within the window (5,1) to (7,7). This means that the discussions in the second workshop will strive to shift the tasks currently located in the human assembling and monitoring area towards the designed SoPIs either by improving tools, equipment and work instructions or designing a completely new system.

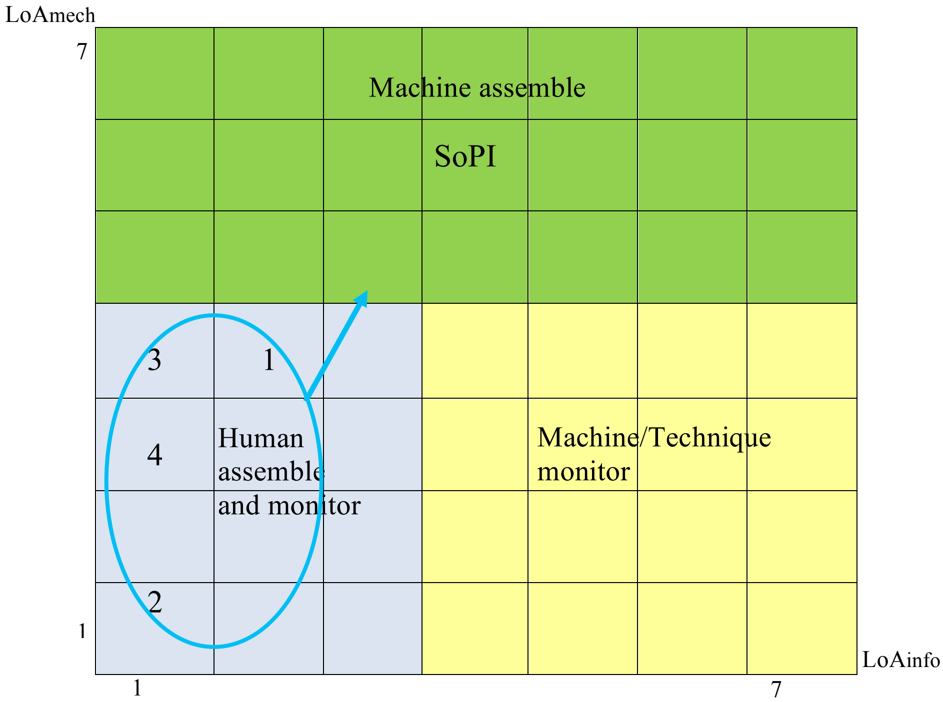


Figure 40: The SoPI matrix for operator 3 at workstation 4

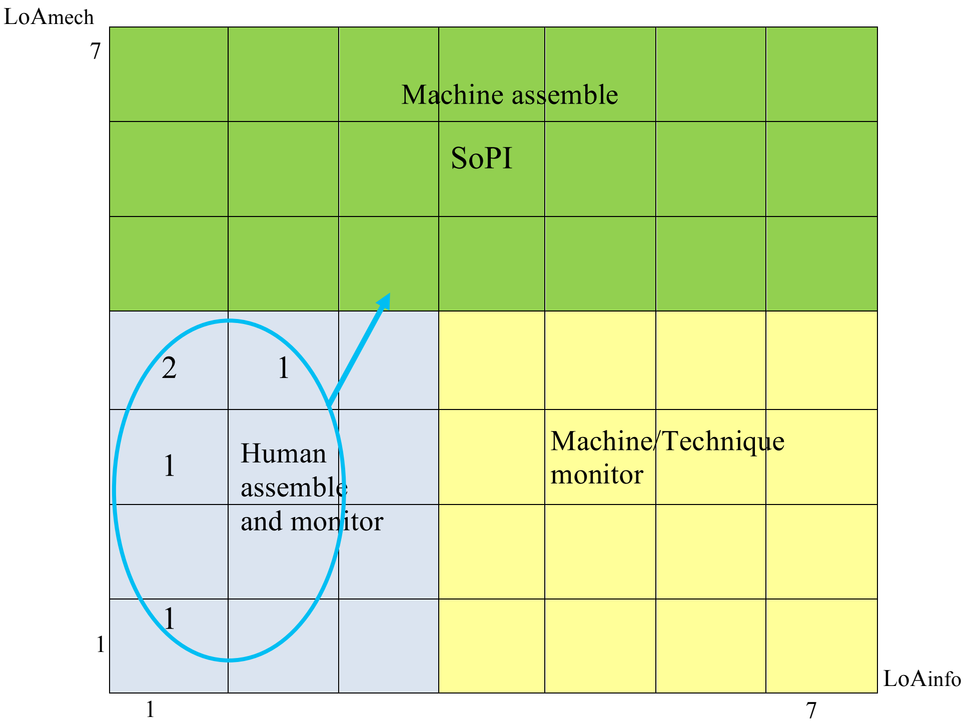


Figure 41: The SoPI matrix for the operator at the VIP-cross member subassembly line

4.7.3 The second workshop

The improvement suggestions generated from the second workshop along with the project members' ideas are listed below. The suggestions range from improving the tools and equipment to the implementation of automated systems.

i. Use lifting tool to get the components from the material pallets
ii. Use movable fixture at the VIP-cross member subassembly line

iii. Change the material of the rivet tool to reduce its weight
iv. A robot that gets the components from the material pallet and places them on a fixture
v. Human-robot collaboration where a robot picks the components and the operator guides the robot to place them
vi. Use rivet tool that automatically adjusts itself and fasten the rivets based on information received
vii. A robot fastens the rivets
viii. Implement push button or other sensor systems to handle the tools and equipment
ix. Use adjustable automatic screwing tool
x. Use AGV to shift the VIP-cross member to the main line

The first idea is to provide the operator with a lifting tool to pick the components. The discussion during the workshop pointed out that there was a lifting tool intended to pick the components from the pallets. However, this tool was not used by the operators because either they did not know about it or felt it easier and faster to pick the components using their hands. The measurement results presented in Chapter 4.3.2 did not include the existing lifting tool because it was not visible at the workstation.

The second idea refers to using a movable fixture that the operator can move with and place the components on it. This idea was inspired from the solutions used in other subassembly lines in the Tuve plant.

The third idea aims to make the rivet tool lighter by changing its material. This makes the tool weigh less and easier to handle.

The fourth idea is to implement a robot that is responsible to pick and place the components on the fixture. An integrated sensor system helps the robot to identify the components and correctly place them.

The fifth idea proposes a collaborative system where the pick and place of heavy components is shifted to a robotic system while the operator is only responsible for guiding the robot to accurately place them.

The sixth idea refers to a solution where the rivet tool adjusts itself depending on the type of chassis coming in the main line. The tool uses the company’s information system to adjust itself by moving in X-direction along the chassis and then lowers itself in Z-direction to reach the start position.

The seventh idea aims to shift the riveting task towards a robotic system. The robot uses vision system to move the tool to the position where the task is to be carried out and also detects the position of the rivets and fastens them. The rivets are silver colored so that the robot can easily identify them.

The eighth idea aims to handle the rivet tool using push button. The operator presses the push button to activate the tool so that it descends to the start position where the task is to be carried out. There onwards, the operator takes control of the tool and fastens the rivets.

The ninth idea refers to a screwing tool that is automatically controlled. The tool descends at the screwing position and tightens the screws without the involvement of the operator. After tightening the screws, the tool automatically returns.

The tenth idea has the motive to deliver the assembled VIP-cross member using a robotic system where the operator does not need to move the fixture instead an Automatic Guided Vehicle (AGV) transfers the product to the main line.

Figure 42 and Figure 43 below illustrate HTAs presented in Chapter 4.7. In the HTAs the listed improvement suggestions have been included to illustrate where they can be used. As seen, the suggestions are usable for improving the tasks either in the VIP-cross member subassembly line or for operator 3 at workstation 4.

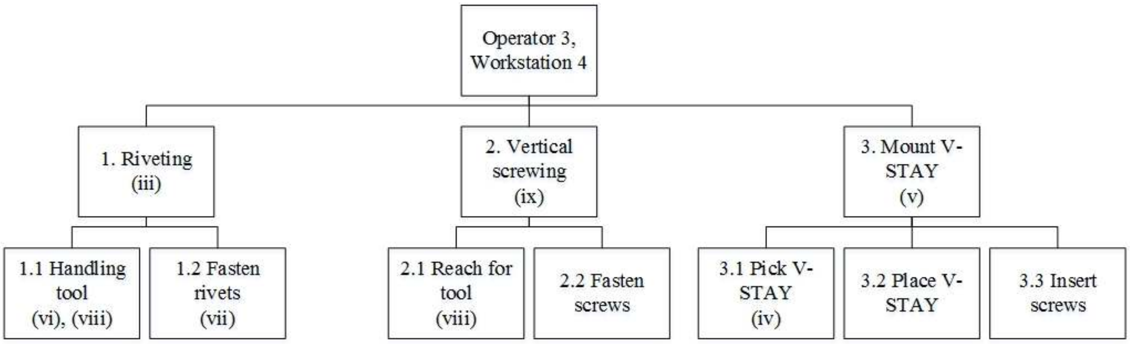


Figure 42: HTA for operator 3 at workstation 4 showing where the improvement suggestions fit

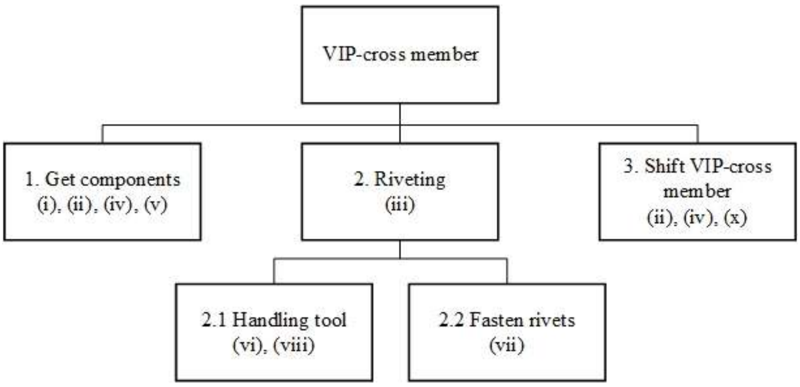


Figure 43: HTA for the operator at the VIP-cross member subassembly line showing where the improvement suggestions fit

4.8 Generated conceptual solutions

After the second workshop, the ideas listed in Chapter 4.7.3 were sorted out by the project members who thereafter designed short and long term conceptual solutions. The solutions are divided into short and long term because during the second workshop difference of opinion was found between the top management personnel and the operators. The focus of the top managers was to fully automate the system whereas the operators' point of view was to make small improvements in the existing system. Short term solutions focus on improving existing tools and equipment in the current system and the long term solutions are focused towards changing the whole system. The proposed conceptual solutions are grounded on the project members' ideas combined with improvement suggestions generated during the second workshop. Moreover, the industrial automation case studies presented in Chapter 2.8 stands as base for generating the concepts. The solutions aim to solve the identified problems in the current state and thereby fulfill the TfC.

All the solutions presented below are conceptual designs which only give suggestions of how the tools and equipment presented in Figure 26 and Figure 27 could possibly be improved. Moreover, descriptions of how to use or control them are suggested. No implementation is carried out in the assembly line because it would be stepping outside the scope of this thesis. The tools and equipment that need to be invested in are listed but cost calculation about them is not given because it was not included in the scope of this study.

4.9 Short term solution – workstation 4

The short term solution for operator 3 at workstation 4 is focused on finding better equipment for the rivet tool.

4.9.1 Mechanical improvements

The improvement on the LoA_{mech} is to design equipment that allows better handling of the rivet tool. The solution was inspired from the improvement suggestions iii and viii listed in Chapter 4.7.3 above. The improvements are as follows;

Free standing Jib crane – Figure 44 shows a Jib crane positioned close to the workstation on which the rivet tool is mounted. The crane can rotate 360 degrees, can handle more than 200 kilograms and has a reach of up to 6 meters. The operator can easily fetch, use and return the tool without putting in a lot of effort. A handle with control buttons is attached with the rivet tool which makes it easier for the operator to handle it. Moreover, the operator can tilt the tool at different angles using the buttons. Additionally, the design of the tool allows the operator to stand in an upright posture while fastening the rivets. The LoA_{mech} remains the same as in the current system.

4.9.2 Cognitive improvement

The LoA_{info} has been improved where the reach of the Jib crane is giving information to the operator about the maximum reach. Moreover, pictorial representation of how to use the tool is placed at the workstation. Furthermore, a television screen is placed at the workstation which shows information about the location of the rivets on the chassis. The rivet tool is connected to MONT/AAS which tells the operator about the amount of rivets to fasten by displaying it on the screen. After the operator fastens all the rivets, the screen signals green indicating that the task is completed. These improvements increase the LoA_{info} for the riveting task to the level three.

4.9.3 Concept layout

Figure 44 illustrates concept design of the short term solution at workstation 4. Immediately after the chassis arrives at the workstation, the operator walks over to the Jib crane and grabs the rivet tool. Then moves close to the start position and begins to fasten the rivets using the control buttons. The tool can be moved in z direction and can be tilted to accurately reach the rivets. After fastening all the rivets, the operator returns the tool. The other tasks mounting the V-STAY and the vertical screwing are carried out in similar way as in the current system. The television screen gives information to the operator about the exact number of rivets to fasten and signals green when all the rivets are fasten.

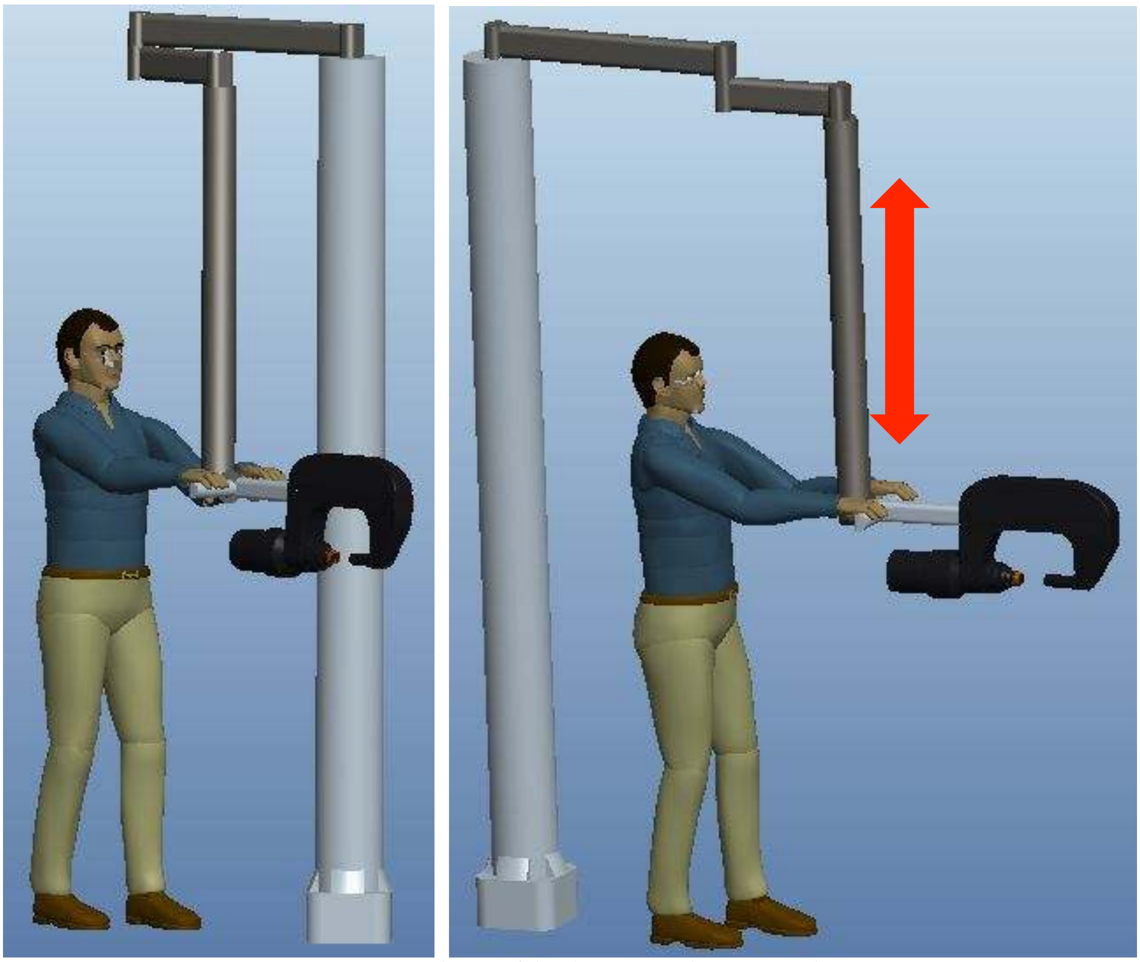


Figure 44: Concept design of the short term solution at workstation 4

4.9.4 HTA

The HTA for the solution described above is similar to that of the current state presented in Figure 42. The operator performs the tasks similarly as in the current system and therefore the LoA_{mech} remains the same. However, theoretically the handling of the rivet tool is ergonomically improved.

4.9.5 LoA matrix

Figure 45 illustrates LoA matrix for the short term solution where the LoA for the riveting task has been improved from (4,1) to (4,3) but remains the same for the other tasks. The blue circle shows the current LoA for the riveting tasks and the green circle shows the improved LoA for it.

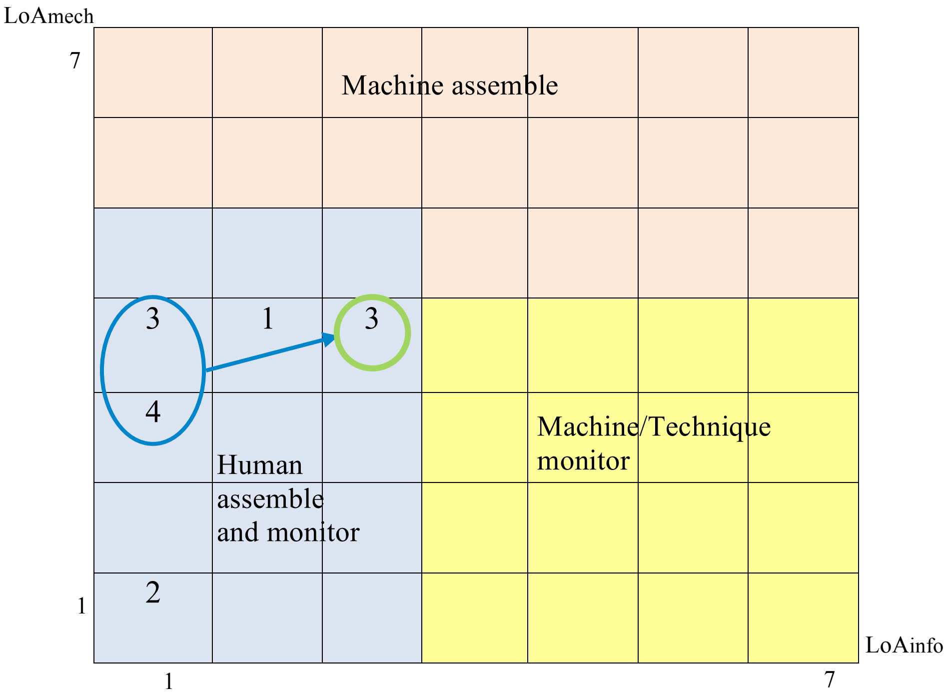


Figure 45: The final LoA matrix for the short term solution at workstation 4

4.10 Long term solution – workstation 4

The long term solution aims to implement new tools and equipment that perform the tasks independently or assist the operator.

4.10.1 Mechanical improvements

The improvements on LoA_{mech} are generated by combining the following improvement suggestions; iii, v, vi, vii, ix. The improvements on the LoA_{mech} are as follows;

The rivet tool - Figure 46 illustrates the rivet tool mounted on a rail crane hanged above the workstation. The tool is movable in x and z directions based on the information received from SPRINT and FCS. It can be tilted at different angles in order to correctly position itself on the rivets before fastening them.

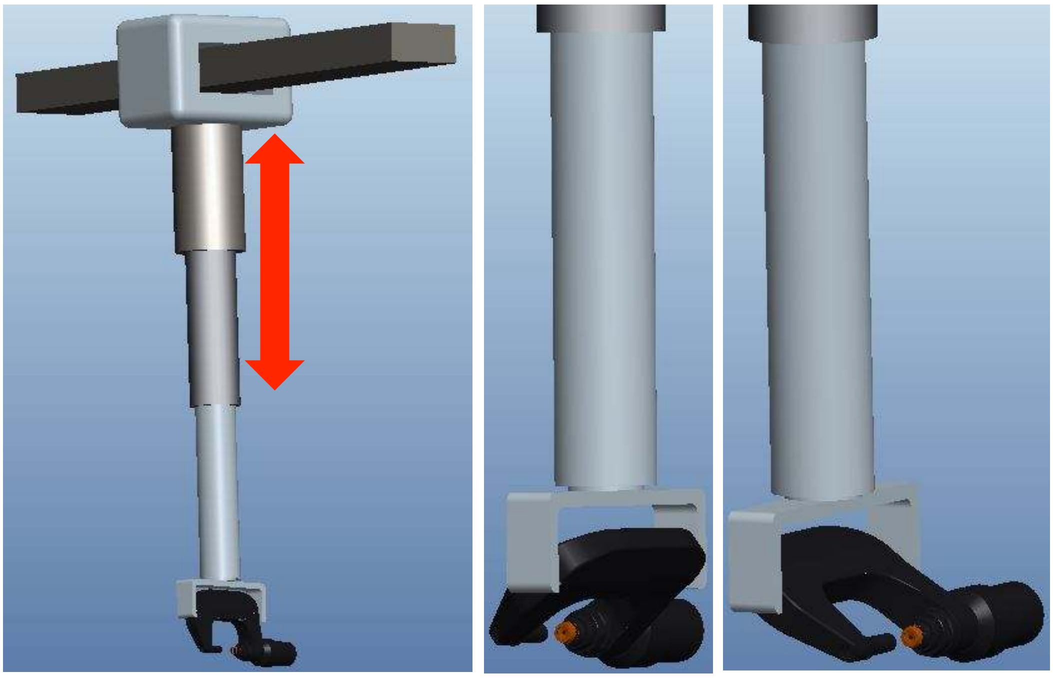


Figure 46: Concept design of the rivet tool mounted on a rail crane

Silver colored rivets - The rivets are silver colored for easy identification of their position on the chassis by the vision system attached to the rivet tool.

Automatic screw driver - Figure 47 shows the automatic screw driver which is also mounted on a rail crane above the workstation. The tool is controlled using the SPRINT system where the head is adjusted based on the type of chassis coming at the workstation. The tool is designed to allow obstacle avoidance on the chassis.

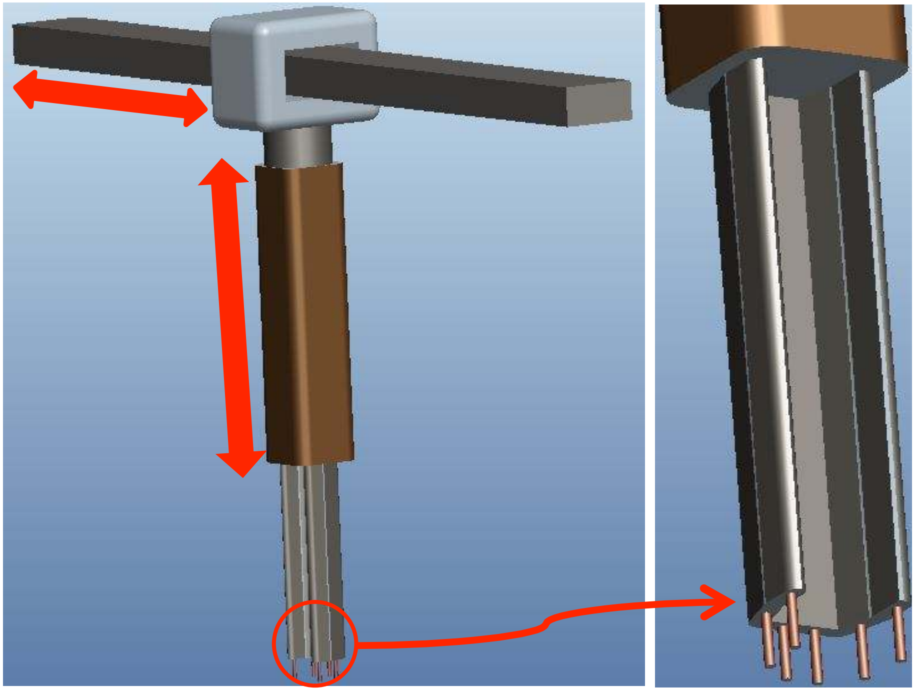


Figure 47: Concept design of the automatic screw driver

Screws - Figure 48 exemplifies the type of screws usable with this automatic screw driver. The screws are threaded on both sides to eliminate holding it with a spanner from beneath as in the current system.

Figure 48: Example of a threaded screw used in other subassembly line in Tuve Plant

FANUC Robot CR-35iA – This is a collaborative robot with payload capacity of 35 kilograms. The robot has forward reach of approximately 1.8 meters and backward reach of approximately 1.1 meters. The robot can be used in assembly environments together with the operator without safety fences. It is integrated with a stop function that activates whenever it comes in contact with an operator to avoid injuries. The robot iRVision system allows it to pick components after accurately locating them in the pallets and places them at the desired spots ("Collaborative industrial robot FANUC CR-35iA", 2016). Figure 49 shows a FANUC CR-35iA which is estimated to be capable of picking and placing V-STAY. See Appendix I for weight of the V-STAY.

Figure 49: FANUC CR-35iA Robot - Adapted from "Collaborative industrial robot FANUC CR-35iA" (2016)

Material pallet – The V-STAY is placed on a conveyor pallet where one V-STAY replaces the other after the robot picks one of them.

The improvement suggestions listed above has improved the LoA_{mech} to level six.

4.10.2 Cognitive improvements

One improvement of the LoA_{info} is to incorporate SPRINT and MONT with the rivet tool and the automatic screw driver so that they can automatically control themselves and execute the tasks. SPRINT tells the tools about the exact location of the rivets and screws while MONT gives the information about the exact number of rivets and screws that are to be fastened on each chassis. Additionally, integration of vision system on the rivet tool for accurately identifying the position of the silver colored rivets is another improvement of the LoA_{info}. The vision system also allows the tools to move above the chassis without colliding with other components. The FANUC robot also uses vision system to identify and pick the correct V-STAY from the material pallet. These improvements increase the LoA_{info} to level six.

4.10.3 Concept layout

Figure 50 below shows concept layout of the long term solution at workstation 4 which is now divided into workstation A and B. Workstation A is a fenced robot cell where the riveting and screwing tasks are carried out and mounting the V-STAY and inserting the screws into it are shifted to workstation B.

At workstation A, the rivet and screwing tools are hanged on a rail crane over the workstation, illustrated in Figure 53. Immediately as the chassis arrives at the workstation the rivet tool activates and travels to the start position. Then descends and fasten all the rivets. The tool is controlled using SPRINT and MONT where it receives specific information about the chassis. The rivets are silver colored and are inserted by the operator at the previous workstation in the line. The rivet tool identifies the position of the rivets using SPRINT, MONT and the vision system. After fastening all the rivets, the tool automatically returns and adjusts itself for the next chassis. As the riveting goes on, the automatic screw driver activates simultaneously, travels to the start position and descends to tighten the screws. The tool head adjusts itself according to the type of screws and is controlled in the same way as the rivet tool.

After the riveting and screwing are done, the chassis moves to workstation B where human-robot collaboration is used to mount the V-STAY. The robot activates, picks the component and carries it to the chassis. Thereafter, the operator guides the robot to place the V-STAY into the chassis and then inserts the screws in it. The operator is also responsible to monitor the assembly procedure at this workstation.

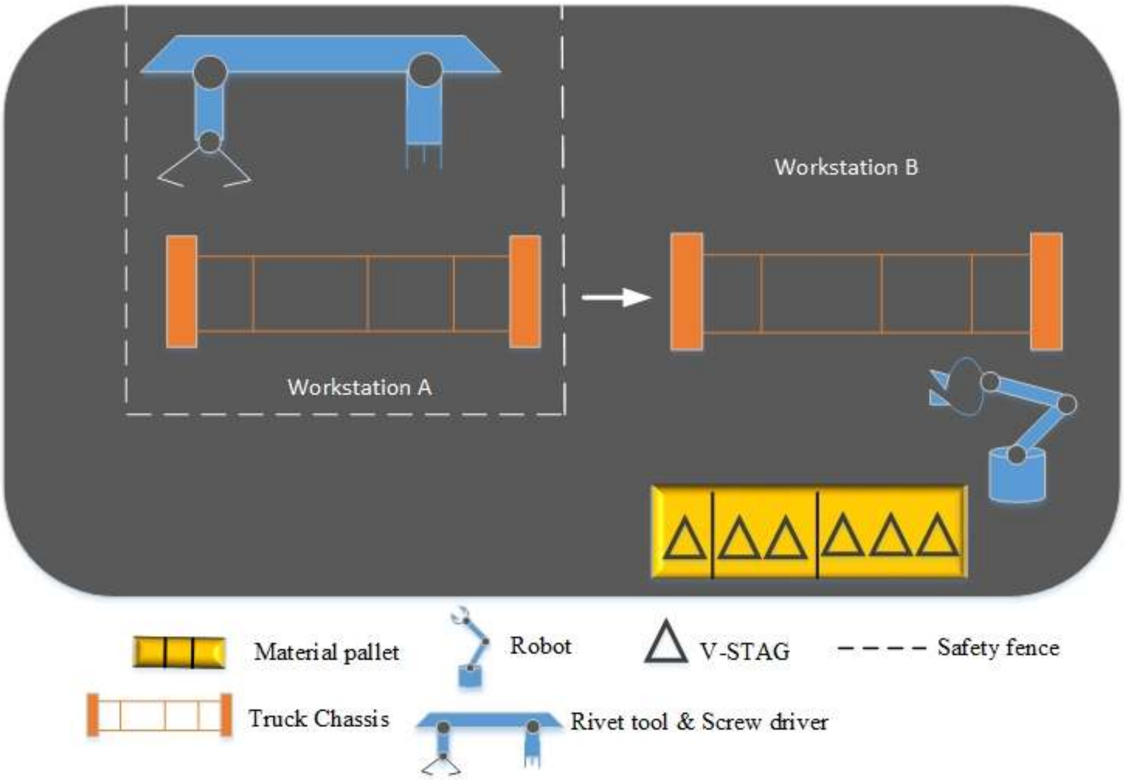


Figure 50: Concept layout of the long term solution at workstation 4

4.10.4 HTA

Figure 51 illustrates a new HTA for the long term solution described above where the riveting and vertical screwing are totally automatic. However, in case of mounting V-STAY it is human-robot collaboration where the robot picks the V-STAY and the operator only guides the robot to place the V-STAY into the chassis. Thereafter, the operator also inserts the screws in it.

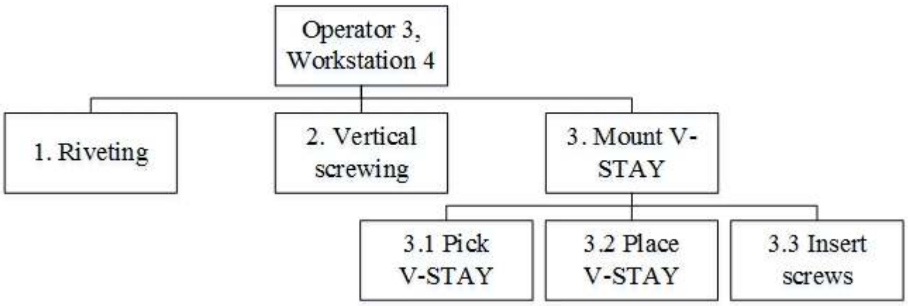


Figure 51: HTA including the tasks for the long term solution at workstation 4

4.10.5 LoA matrix

Figure 52 below illustrates a LoA matrix for the long term solution at workstation 4 where the LoA for the riveting, vertical screwing and picking of V-STAY is improved to (6,6). Mounting the V-STAY is done in a collaborative environment where the picking of the V-STAY is done by a robot but placing it into the chassis and inserting screws in it are done through collaboration between the robot and the operator because they require high precision. The LoA_{info} has been improved to level three as the operator gets instruction about when and where to guide the robot in order to place the V-STAY and insert the screws into it. The LoA for these tasks is improved to (1,3). The tasks in the current system are circled blue which are improved in the new system encircled green.

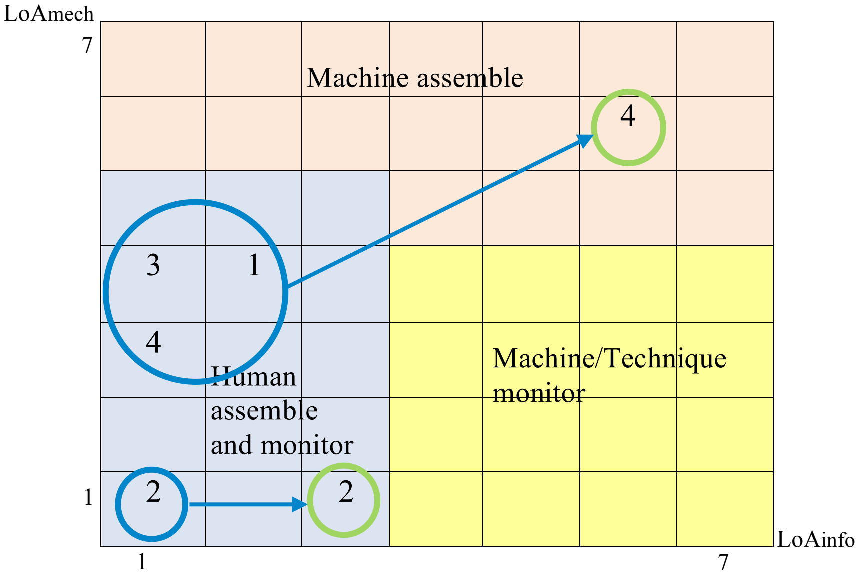


Figure 52: The final LoA matrix for the long term solution at workstation 4

4.10.6 Concept design of rail crane

Figure 53 shows concept design of the rail crane where the rivet and screwing tools are mounted over workstation A. The design of the rail crane allows the tools to move all over the workstation. This concept proposes that the workstation is dedicated to only riveting and screwing. The workstation is fenced and equipped with alarm system to prevent humans from entering. The tools are connected to SPRINT and FCS for controlling their movement in x and z directions to reach the desired positions on the chassis. The other tasks which include mounting the V-STAY and inserting the screws into it using human robot collaboration are shifted to workstation B, illustrated in Figure 50 above. In this concept design, both tools work on opposite sides of the chassis and progressively move to the other side after completing the tasks on one side.

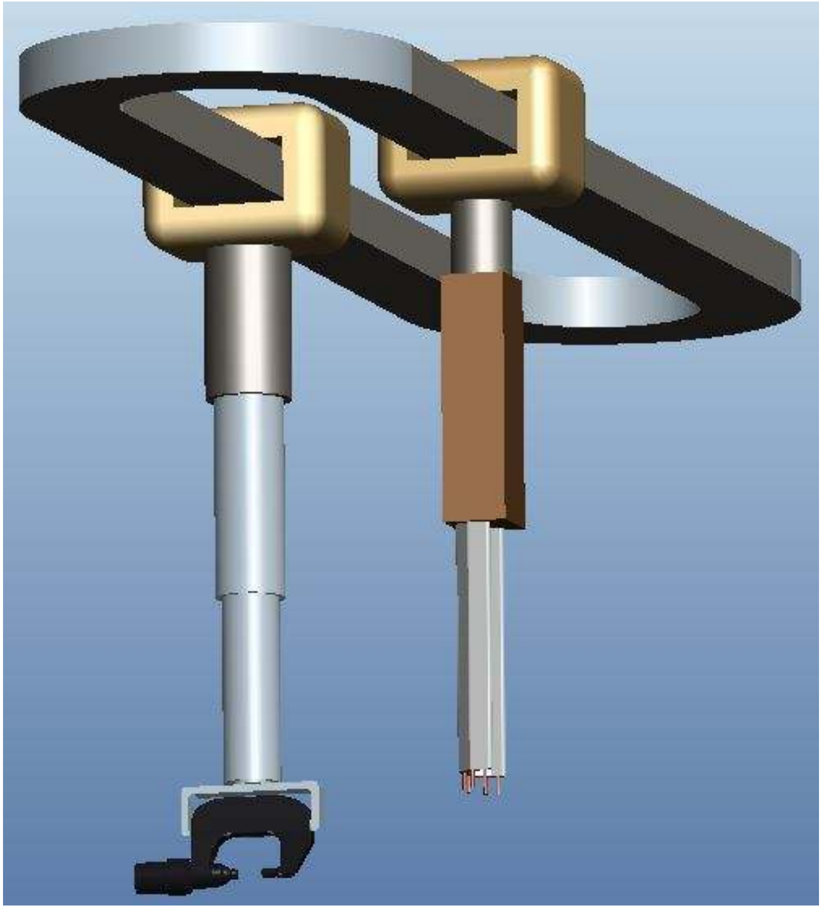


Figure 53: Concept design of a rail crane with the rivet tool and screwing tool mounted on it.

4.11 Short term solution – VIP-cross member subassembly line

The goal of the short term solution at this workstation is to generate innovative ideas within the existing system without changing it completely.

4.11.1 Mechanical improvements

To improve the LoA_{mech} for assembling the VIP-cross member, the listed improvement suggestions; i, ii, and viii have been combined. The improvements are as follows;

Material pallets - The material pallets are placed at appropriate heights according to the VASA model presented in Chapter 2.7. Placing the material pallets at appropriate height will prevent the operator from bending, stretching and twisting while picking the components.

Lifting tool - The operator gets the components using a lifting tool which increases the LoA_{mech} for this task to level four. Figure 54 shows the concept design of the lifting tool which is attached on airlift equipment and is controlled using hand controller. The head of the tool is magnetic which allows proper gripping of the components. The opening range of the tool is changeable depending on the size of the component.

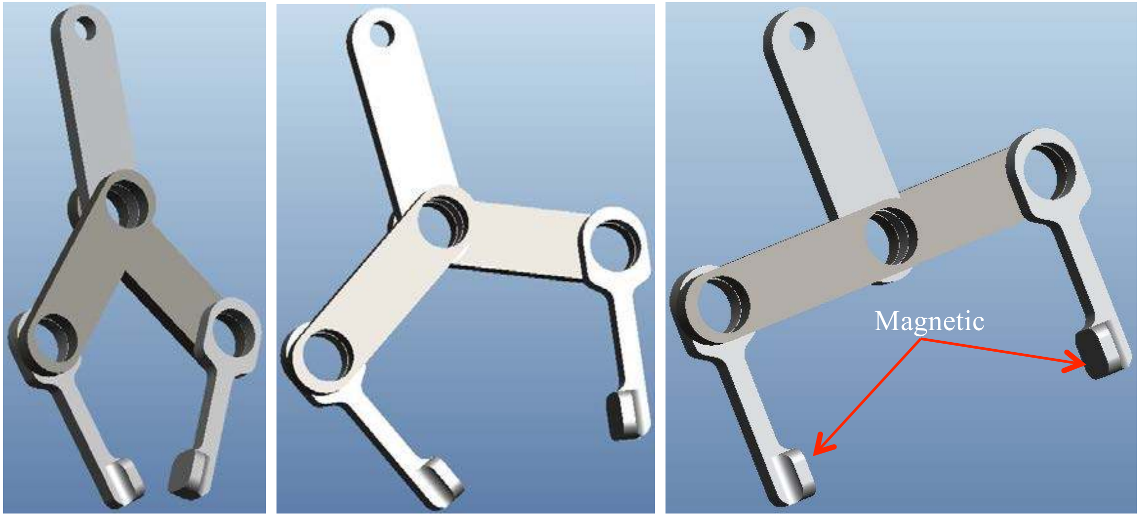


Figure 54: Concept design of the lifting tool at the VIP-cross member subassembly line

Movable fixture - Figure 55 below exemplifies concept design of a movable fixture integrated with wheels and locking system. Wheels allow the operator to move with the fixture and rotate it easily while fastening the rivets. The locking system allows the operator to fixate the wheels so that the fixture does not move. The fixture is adjustable so that it suits different heights of the operators. The support at the center is to keep the middle Cross member stable and the four pins are where the Anchorage VIP and Anchorage cross are placed. See Appendix I for the Glossary.

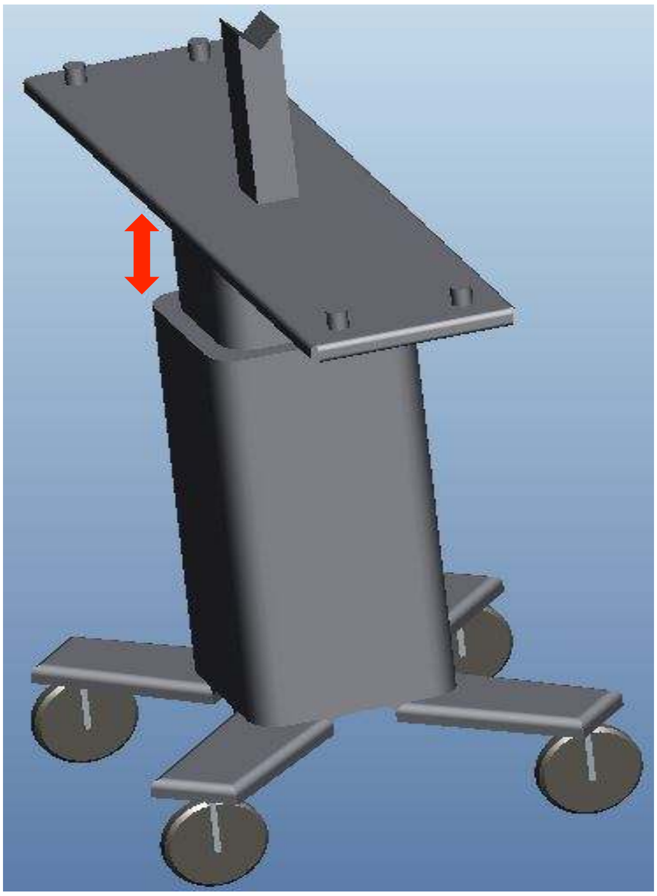


Figure 55: Concept design of the movable fixture for the VIP-cross member subassembly line

The rivet tool - The operator uses the same rivet tool as in the current system to fasten the rivets. However, the tool is attached on a rail crane hanged at appropriate height above the workstation, shown in Figure 56. The tool can be call down in x direction with the help of a push button and a handle with control buttons has been designed so that the operator can easily grab the tool and press the button to fasten the rivets. Moreover, the control buttons allows the operator to tilt the tool at different angles.

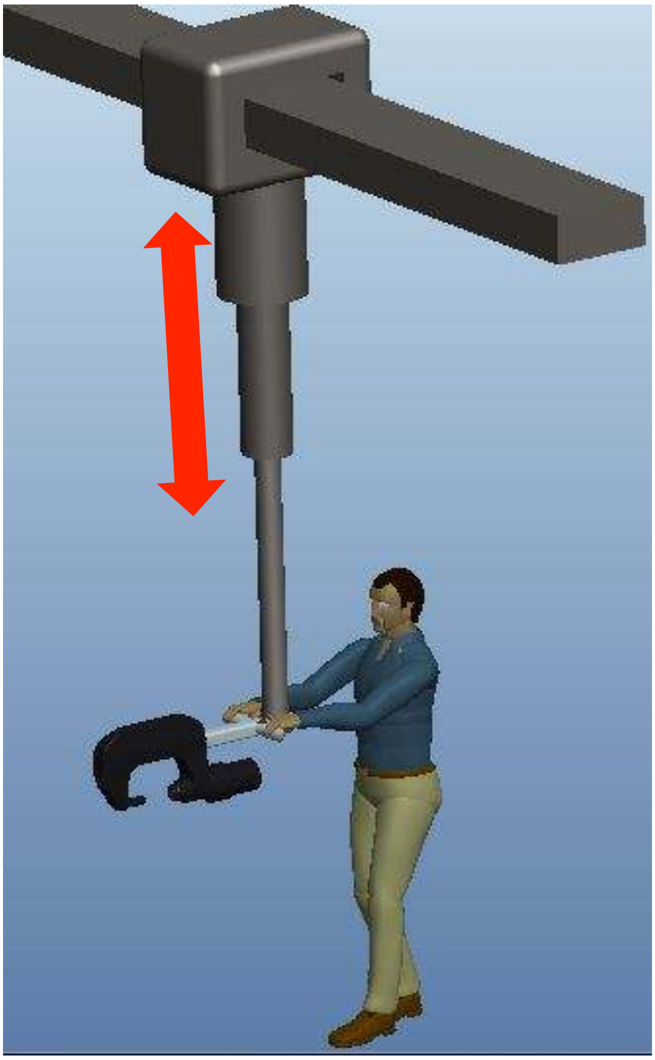


Figure 56: Concept design of the rivet tool for the short term solution at the VIP-cross member subassembly line

Push button - The operator calls the rivet tool down to the start position by pressing a push button and after the rivets are fastened commands it to return pressing the button again. Figure 57 exemplifies a push button that is suitable to use.

Figure 57: Push button – Adapted from "Industrial Push Buttons - Signaworks" (2016)

These improvement suggestions have improved the LoA_{mech} to level three and four.

4.11.2 Cognitive improvements

The major improvement of LoA_{info} is to provide visual instructions about the lifting tool which helps the operator to easily identify it. Moreover, the instructions for activating and using the rivet tool as well as moving the fixture are also available for the operator at the workstation. In this solution, a television screen is also used for similar purposes as mentioned in Chapter 4.9.2. These improvements increase the LoA_{info} for these tasks to level three.

4.11.3 Concept layout

Figure 58 illustrates the concept layout of the short term solution at the VIP-cross member subassembly line. The material pallets are placed at appropriate height in the material racks to ease picking of the components. The operator moves with the fixture close to the pallets and pick and place the components using the lifting tool. Moving the fixture close to the pallets shortens the distance for getting the components. Then, the operator picks the rivets from the bin located on the material rack and inserts them on both sides of the VIP-cross member. After this, the operator moves the fixture at a marked spot below the hanging rivet tool and locks it. Thereafter, presses the push button to call the rivet tool at the start position where the operator takes control of the tool to fasten the rivets on one side of the VIP-cross member. Then, rotates the fixture and fasten the rivets on the other side. This prevents movement of the operator with the tool from one side of fixture to the other. After fastening all the rivets, the operator presses the push button again to return the tool. In the end the operator delivers the assembled product by moving the fixture to the buffer that can store five VIP-cross members. This eliminates the task of lifting the VIP-cross member from the fixture to the carrier before delivering it to the main line. Using a specific number of moveable fixtures indicates how many VIP-cross members are needed to be assembled. An empty buffer space indicates that there is a need to assemble the VIP-cross member.

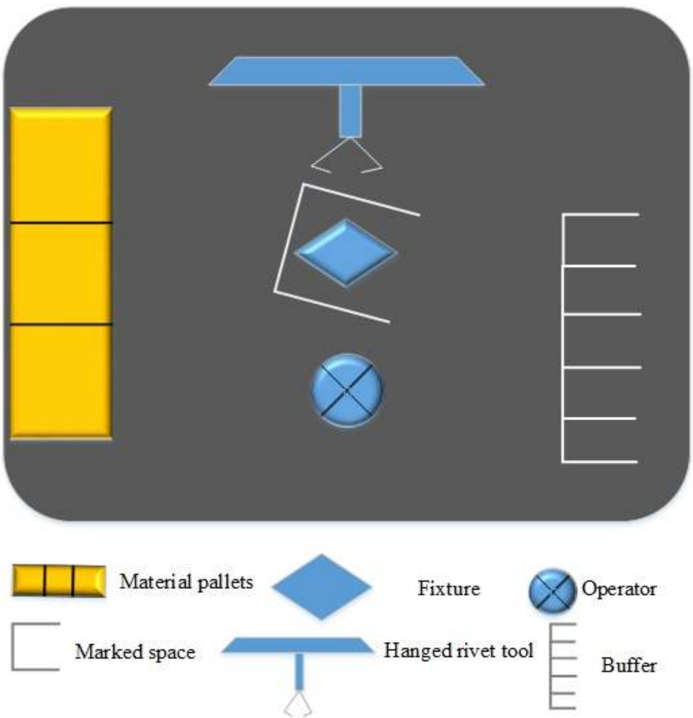


Figure 58: Concept layout of the VIP-cross member subassembly line

4.11.4 HTA

Figure 59 shows new HTA for the tasks carry out by the operator at the VIP-cross member subassembly line. The task “get components” relates to the picking and placing of the components on the fixture and inserting the rivets. “Move fixture” includes the operator movement with the fixture from material pallets till the delivery point in the main line.

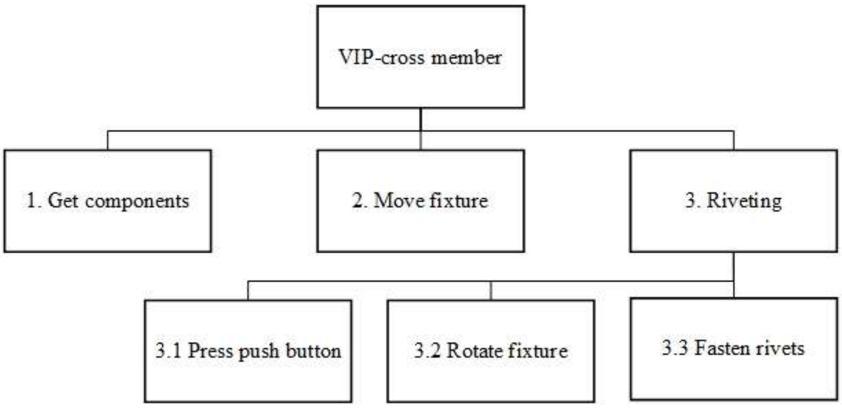


Figure 59: HTA including the tasks for the short term solution at the VIP-cross member subassembly line

4.11.5 LoA matrix

Figure 60 illustrates LoA matrix for the short term solution at the VIP-cross member subassembly line. In the matrix, the LoA for moving the fixture is (3,3) and (4,3) for the rest of the tasks. In this new state, the operator performs all the tasks with the support of tools and with instructions of how to use them. Moreover, the task of shifting the VIP-cross member from the fixture to the carrier is eliminated by the use of the movable fixture. Now the operator assembles the VIP-cross member on the movable fixture and delivers it directly to the buffer in the main line. The tasks in the current system are circled blue which are improved in the new system encircled green.

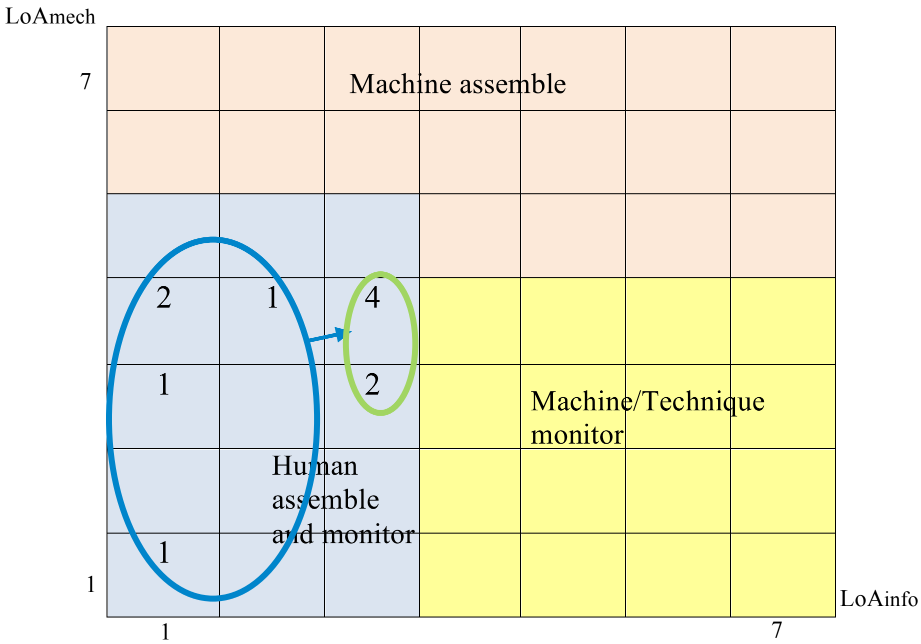


Figure 60: The final LoA for the short term solution at the VIP-cross member subassembly line.

4.12 Long term solution – VIP-cross member subassembly line

The main goal of the long term solution is to completely change the current way of working at the VIP-cross member subassembly line. This means, to find equipment and processes that assemble the VIP-cross member with less involvement of the operator.

4.12.1 Mechanical improvements

To improve the LoA_{mech} for assembling the VIP-cross member the listed improvement suggestions; iii, iv, v, vi, viii, and x have been combined. The improvements are as follows;

Material pallets – The components are still stored in material pallets where their positions in the pallets are defined so that a robot knows the position and sequence of picking the components. Each pallet is dedicated to one type of component and contains a specific number of it.

FANUC Robot CR-35iA - Picking and placing of the components is shifted to a similar type of collaborative robot presented in Figure 49 above.

The rivet tool – It is similar to the one presented in Figure 46 above. The tool is hanged above the workstation at appropriate height and gets activated using SPRINT, MONT and vision system after the AGV arrives at the marked spot. After fastening all the rivets, the tool automatically returns.

Silver colored rivets – The rivets used are marked with silver color so that the vision system can easily identify their positions accurately on the chassis before the tool fastens them.

AGV – The fixture is incorporated on the AGV which gets activated only when there is a demand of the VIP-cross member in the main line. The control system of the AGV is connected to SPRINT from where it receives information about when to deliver the VIP-cross member in the main line. The AGV moves on a defined path on the floor.

These suggestions improve the LoA_{mech} to level five and six.

4.12.2 Cognitive improvements

Improvements of the LoA_{info} include for instance force control sensors and vision systems integrated with the robotic systems and the rivet tool. These improvements shift most of the tasks to be at level five on the LoA_{info}. This is due to the fact that the technique monitors most of the information during the assembly of the VIP-cross member.

4.12.3 Concept layout

Figure 61 illustrates a concept layout of the long term solution at the VIP-cross member subassembly line. In this solution, the assembly procedure of the VIP-cross member initiates when the AGV receives information that the product is needed in the main line. The AGV moves close to the material pallet and the components are placed on it through human robot collaboration. Here, the robot picks the components and the operator guides it to accurately place them on the AGV. After placing the components, the operator inserts the silver colored rivets on both sides of the VIP-cross member. Thereafter, the AGV moves to the marked spot and the vision system calls the rivet tool to descend at the start position. The tool descends, detects the position of each rivet using the same vision system and fastens the rivets on one side of VIP-cross member. Thereafter, moves to the other side and fastens the rivets. After all the rivets are fastened, the tool returns and the AGV deliver the VIP-cross member to the main line. Depending on the daily production volume of the VIP-cross member specified number of AGV's can be used. The workstation is partly fenced and is equipped with alarm sensors to prevent the operator from entering where the automated system is located.

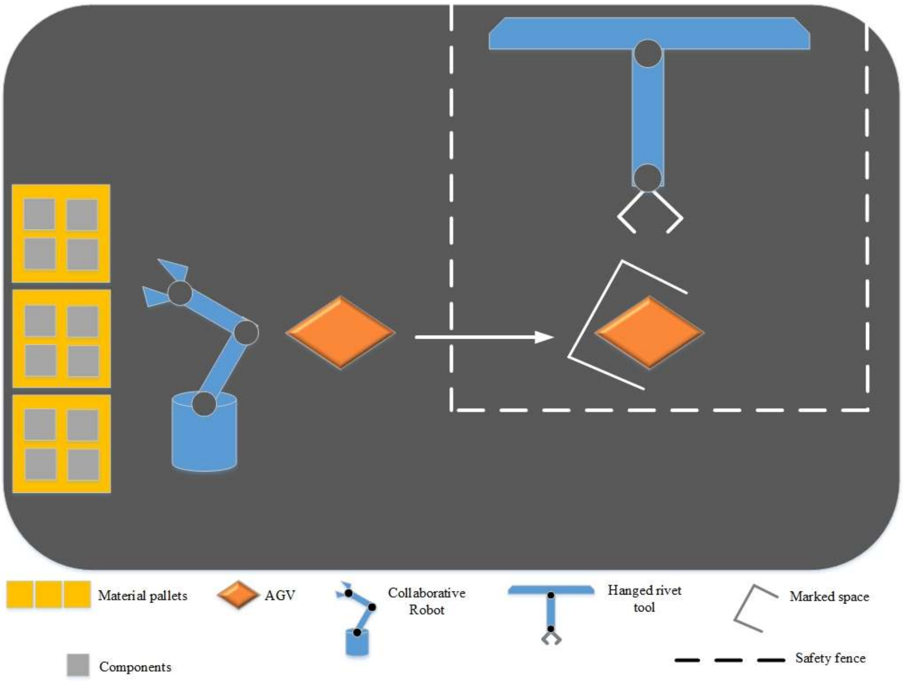


Figure 61: Concept layout of the long term solution at the VIP-cross member subassembly line

4.12.4 HTA

Figure 62 illustrates a new HTA for the solution described above, where the first task "position AGV" relates to the automatic positioning of the AGV at the marked spot for riveting and at the main line where it delivers the product. The second task "get components" entails the picking and placing of the components onto the AVG through collaboration between the operator and the robot, and inserting of the silver colored rivets by the operator. The last task "riveting" is done automatically by the rivet tool which descends, fastens the rivets and returns.

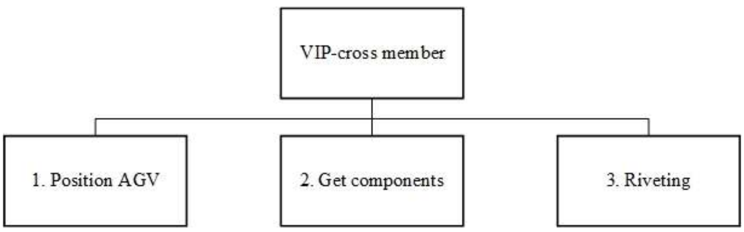


Figure 62: HTA including the tasks on functional level for the long term solution at the VIP-cross member subassembly line

4.12.5 LoA matrix

Figure 63 below illustrates the LoA matrix for the long term solution at the VIP-cross member subassembly line. In the matrix the LoA for getting the components is (5,5) and (6,5) for the other two tasks. Inserting the silver colored rivets into the VIP-cross member is at (1,1) as it is still done by the operator. Even though this task has not been shifted from the operator, the ergonomics of the operator is improved because the AGV can be adjusted to appropriate heights in order to avoid bending as in the current system. It is clearly seen that all the tasks are located in the area where the assembly work is done by a machine. Monitoring of the assembly procedure is partly done by the machine and also by the operator. The current LoA for the tasks in the current system are circled blue which are improved in the new system encircled green.

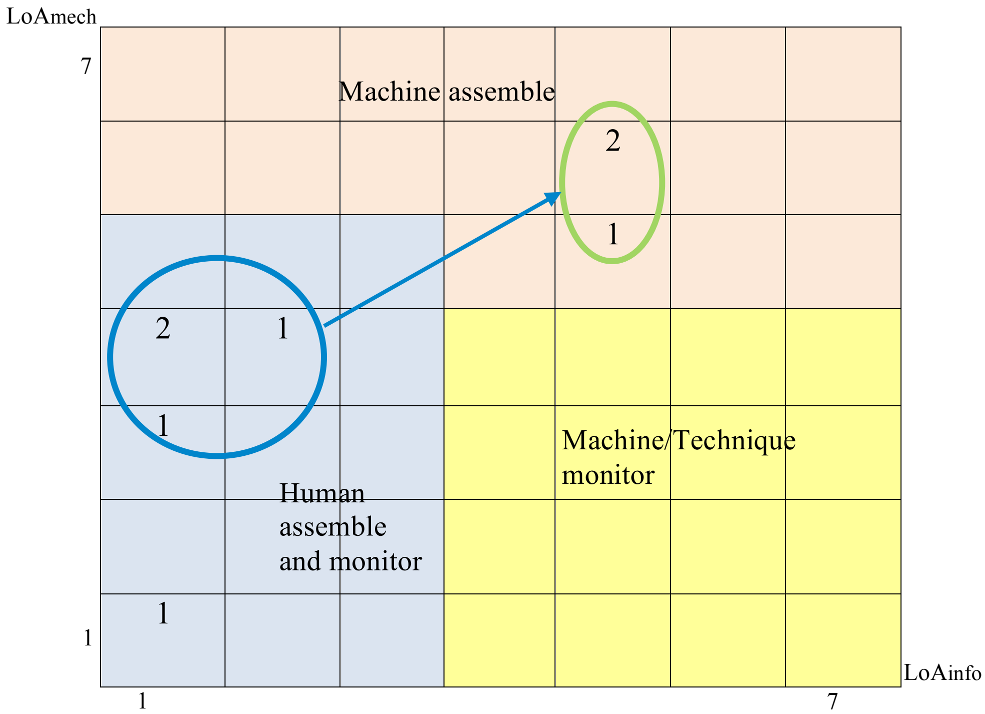


Figure 63: The final LoA for the long term solution at the VIP-cross member subassembly line

5 Discussion

This Chapter discusses and analyzes the empirical results presented in the previous Chapter. It also briefly discusses contrast between the results and the theory Chapter.

5.1 The implementation of the Dynamo++ methodology

In this study, the Dynamo++ methodology has been adapted in order to achieve the purpose. In this regard, the third step of the methodology which is to do a VSM to map the flows of the main processes and information has been deemed unnecessary. This is because the study is based on the selected operators and not on the whole system. Even though, VSM gives good understanding about the system, its implementation would mean stepping beyond the scope of this study.

The final phase of the methodology is to implement the suggested solutions on the system and to do follow-ups (Fasth, 2012). However, the request by GTO was only to communicate the requirements and benefits of the suggested improvements theoretically and therefore no real implementation has been carried out. The conceptual solutions based on the improvement suggestions have been developed but it yet remains to see how they would impact the assembly procedure of GTO.

According to Fasth (2012), Dynamo++ is an iterative method applied numerous times to get refined results. However, this has not been done in this thesis because the project time does not allow it and also due to busy schedule of the employees in the company. It is important to mention that even though the methodology was implemented only once, the purpose of this thesis is still achieved.

As mentioned by Fasth (2012), Dynamo++ can be combined with other scientific tools to avoid over automation and sub-optimization. In this regard, the methodology has been combined with REBA and the analysis of perceived pain based on one of the TfCs stated by GTO which is to improve the ergonomics for the operators.

In addition to the theoretical background of the Dynamo++ methodology explained in Chapter 2.5, using an experienced facilitator during the implementation of the methodology is important. The facilitator will give guidance about how to successfully carry out the phases of the methodology especially while implementing it for the first time. Towards this end, the findings of this thesis can act as the facilitator for GTO to avoid difficulties for the future application of the Dynamo++ methodology.

5.2 The triggers for change

The purpose of implementing the Dynamo++ methodology is clear and it is to fulfill the aim of GTO which is to reduce the manual work and improve the ergonomic conditions for the operators working in the selected workstations. These are used as triggers for changing the current system where the operators are handling heavy tools and components. The selection of the triggers is essential for implementing the methodology and for defining the right scope in order to yield desired results.

During the discussion with GTO for selecting suitable triggers, the project members proposed different trigger like improving quality. However, GTO's focus is to improve the heavy tools and equipment used by the operators. Due to this reason, most discussion about improvements has been centered towards improving the LoA_{mech} while leaving LoA_{info} open. However, it is important to mention that improvements of the LoA_{info} could also solve the problems identified in the current system. This could be done by providing the operators with clear work instructions of how to perform the tasks. It is also worth mentioning that educating the operators about work conditions could also make them aware of how to avoid ergonomic issues. The selected triggers in this study are interrelated to each other because ergonomic problems occur due to large amount of manual work involving handling of the heavy tools and components. From this view, both can be considered as single TfC.

5.3 Comparison with existing theory

According to Shepherd (1998), HTA is constructed by dividing the main goal into sub-tasks and further into operations. Based on this theory, the HTAs constructed in the measurement phase were mostly observational as they give stepwise description of how the operators are performing their tasks. However, these HTAs were not useful during the first workshop because they do not divide tasks on functional level. The functional level in the HTA is important because it gives the possibility to discuss improvements outside the existing system.

Automation strategies discussed by Lotter et al. (2009), and Heilala and Voho (2001) concluded that assembly environments with large product variation are not suitable for fully automated assembly solutions. However, discussions with system engineers at GTO about the proposed long term solutions showed that full automation could be achievable in this case even though the company has large product variation. The discussion assured that GTO has strong base of supporting information systems like SPRINT, FCS, MONT/AAS etc. which could be integrated with the automated solutions. However, the discussion also showed that the company's knowledge in the field of automation is limited and the company therefore needs more knowledge about this field for implementing the proposed solutions.

The long term solutions presented in Chapter 4.10 and 4.12 could result in high costs for GTO which according to Groover (2001) and Frohm et al. (2006) might not be justified. However, it should be mentioned that the long term solutions are only for future considerations. Therefore, further investigation is needed before any conclusions are drawn. The cost calculation of the proposed conceptual solutions has not been done as it was excluded from the scope of this thesis during the planning phase. However, cost calculation is one of the important steps forward to explore further constraints about the generated solutions. For this reason, it is advisable to contact several automation companies. Even though, the findings of Groover (2001) and Frohm et al. (2006) concluded that in case of high costs the implementation of the automated systems is not justified, it is important to mention that the term "high cost" is relative. What one company view as high cost could be a justified cost for another company.

The survey by Frohm et al. (2006) concluded that the aim of implementing automation in production is to achieve healthy working environment and lower the amount of employees. The former reason is aligned with the goal of GTO as the company strives to improve the tools used in the assembly line for improving the ergonomics. However, the latter reason might differ because GTO wants to shift ergonomically bad tasks to other resources than humans and not completely remove the operators from the assembly line.

5.4 The ergonomic analysis

For the REBA analysis, the rear axle suspension variant RADD-TR1 was chosen because the aim was to study the worst case for operator 3 where the most riveting and screwing tasks are carried out. Even though, while installing this variant the operator does the highest amount of manual work, it is worth mentioning that the situation is not the same throughout the working day. This is because this variant is not frequently installed as it is below 10% of the daily production volume of 60 trucks. An approach to base the REBA analysis for the variant where the operator performs average workload would give more realistic evaluation of the operator's postures. This will allow for the study to be based on a normal work distribution of the tasks carried out by the operator.

In order to carry out accurate analysis of postures using REBA, it is important to have sufficient knowledge about how the human body works. This is because it could happen that the postures are misjudged to be ergonomically bad even though they are not. In this regard, the project members consulted the ergonomist at GTO and this thesis examiner familiar with this subject to discuss the results.

The analysis of perceived pain carried out in AviX ergo for the operators indicated concerns. However, the study only included two operators and therefore it is not appropriate to state that the situation is the same for every operator as it could differ based on the operator's experience and physical condition. The discussion about doing more studies of this kind including larger population (operators) is advised. This will give better overview of the situation on which conclusions can be based.

5.5 The workshops

Even though, the Dynamo++ methodology includes a step for doing workshop to decide minimum and maximum LoA, it does not give step-by-step guidelines of how the workshop should be conducted. Since it does not include this information, the project owners are responsible to pioneer a way to organize it in such a way that harvest good discussions points. In this study, the workshop was conducted on two different occasions which helped the participants to focus on a few things at a time.

The second workshop aimed to bring people from different departments of the organization to discuss and generate improvement suggestions. Moreover, it provided the project members with the opportunity to see if the participants have already thought about concrete improvements. However, this was not the case in this study because the suggestions stated by the participants were general. This could be due to the limited available time that the participants had to familiarize with the LoA concept. After the second workshop, the project members sorted out the improvement suggestions to find where they could actually be used as presented in Chapter 4.7.3.

The actors involved during the first workshop had good enough knowledge of how to use the Dynamo++ methodology. However, the workshop did not include experts in the field of automation and therefore, the project members stated clearly that the decided minimum and maximum LoA are based mostly on assumptions. The presence of automation experts could have given the discussions another perspective, resulting in different minimum and maximum LoA than what was actually decided.

During the second workshop, it was experienced that the discussions about generating improvement suggestions were scattered. This was because the decided minimum and maximum LoA were broad. In particular, the LoA_{info} was kept open which made the participants discuss different possibilities but not generate concrete improvement suggestions.

The discussion for improving the LoA for the tasks carried out by the operator 3 at workstation 4 initiated with an argument that installing a robot in the main line is not a good idea. This is due to the fact that robots lack flexibility and also not good at handling large variation. There is also fear that if the technology fails the main assembly line has to stop which is not affordable for the company. The discussions also touched on the point of firstly implementing the automated solutions in the subassembly lines and progressively move towards the main line.

5.6 Short term solution at workstation 4

In this solution, the LoA_{mech} for all the tasks remains the same as in the current system because the operator still performs them manually with supporting tools. However, considering ergonomics as a trigger, this solution solves the ergonomic issues related to handling of the rivet tool. The reason for this is that now the operator stands in an upright posture while performing the riveting task. The rivet tool is now mounted onto a Jib crane which balances out the weight of the tool preventing the operator from applying much force during movement. Additionally, the handle with control buttons helps easier grabbing and operating of the tool compared to the current system where the operator stands in abnormal postures to use it. These control buttons also help to reduce the torque generated by moving the tool using physical strength. Moreover, the LoA_{info} for the riveting task is increased which is attributed to the proper instructions provided on television screen about using the rivet tool. The television screen also informs the operator about the location of the rivets on the chassis and the amount of rivets to fasten. It is important to mention that these instructions ensure that the operator uses the tool in a standardized way to avoid ergonomic issues. Even though this solution proposes better ergonomic conditions for the operator, it is unsure exactly how much it has improved because the solution has not been implemented in the real environment.

As mentioned above, all the tasks are still done by the operator and neither of them is shifted to another resource. Thus, the other TfC which is, to reduce the amount of manual work, is not fulfilled. However, it is important to consider the difficulties related to fulfilling this trigger in the main line in a short period of time because it requires shifting tasks to resources other than humans.

It is mentionable that the rod of the Jib crane could hinder the visibility of the operator while positioning the rivet tool on the rivets before they are fastened. This issue could be addressed by shifting the handle on the side so that the rod does not block the operators' view. Another way to increase the visibility of the operator is to mount the rivet tool on a hollow rod.

The important limitations that need consideration for successful implementation of this solution are as follows;

- Speed
- Weight
- Safety regulations
- Costs
- Physical space

These limitations have been previously elaborated in Chapter 3.8. One of the important limitations to consider is the speed which refers to maneuvering the rivet tool using control buttons which could possibly make the system slow. It could happen that the time for performing the riveting task increase affecting the other tasks. Other limitations worth considering are regarding weight of the tool and safety regulations which refers to whether it is feasible to hang the rivet tool on the Jib crane without injuring the operators. The solution seems to be cost effective because no major investment is needed as the tool remains the same. The physical space could also be a factor to consider as the crane needs to be placed in the main line. This point also leads to the discussion about where to place the Jib crane in order to handle the variation in wheelbase length presented in Chapter 4.2. The placement of the crane at an appropriate position beside the main line could shorten the distances that the operator has to cover with the tool to reach the position of the task.

5.7 Long term solution at workstation 4

In addition to improved ergonomic conditions that this solution proposes, it also almost shifts all the manual work from the operator to an automated system. Now the operator is only responsible for guiding the collaborative robot to place the V-STAY into the chassis and insert the screws into it. A significant increase in LoA_{mech} and LoA_{info} is achieved in this case. This is because the tasks that include heavy lifting of the tools and components are performed by the automated systems. Moreover, increase in the LoA_{info} is because the technology monitors all the tasks performed by it. Also, it helps the operator when and where to mount the V-STAY and place the screws. It is worth mentioning that inserting screws could be shifted from the operator if they are already integrated with the cross member on which the V-STAY is mounted. Possibly this requires change in the design of the cross member and thereby places the demand on the product design engineer. Discussion with design engineer on this point was not done due to time constraints. It is discussable that future solution could result in a fully automatic system where the need of an operator would be unnecessary.

Discussion with the system engineer at GTO highlighted possibility of connecting this solution with existing information systems like; JointCalc, SPRINT and FCS. These systems give information about the type of joints and their position on the chassis. Additionally, MONT/AAS could possibly be used to develop communication between the equipment and the system. However, it could happen that the automated system faces difficulty in finding the exact position of the rivets because the stop position of the chassis might vary. Towards this end, implementation of a vision system could help in finding the exact position of the rivets. The solution also proposes using silver colored rivets to make it easy for the vision system to identify them. Another factor which should be considered is defining the tool path so that it does not collide with the other components and this could also be done by using a vision system.

Currently, the rivet tool weighs approximately 150 kilograms and therefore, it is impossible to allow the riveting task to be performed by a collaborative robot. This is because the maximum capacity today for a collaborative robot is 35 kilograms. On this note, it would require to have an automatic system capable of handling payload over 150 kilograms. Moreover, discussion about changing the design of the rivet tool in order to meet the requirements should be considered. However, this will require discussion with design engineer to explore all the constraints for redesigning the tool.

The screwing tool proposed in this solution was inspired from similar system used in the axle assembly line in the Tuve plant. Design of the tool head is important in order to accurately perform the screwing. Moreover, to use this automatic screw driver requires screws threaded on both sides which allows them to be tighten from upward direction. This eliminates the use of spanner to hold the nuts from beneath as in the current system. Another arguable solution could be to already weld the nuts onto the cross member during manufacturing. These changes put the requirements on the product designer and the manufacturer.

Feasibility of this solution requires considering several limitations as follows;

- Flexibility
- Competence
- Costs
- Safe regulations
- Speed
- Parallel working of resources

The flexibility of the system to handle the large product variation is one of the important limitations to consider. In order to handle the variations presented in Chapter 4.2, SPRINT, FCS and MONT could be used to give the tools accurate information about the sequence of the chassis coming at the workstation and also the amount and position of the rivets and screws on the different chassis. Moreover, to handle the variation would also require having competent and experienced people that could run the system. The cost factor regards investing in processes and competent people to implement the system and keep it up and running.

As previously mentioned, the automated system suited for this solution should be capable of handling heavy tools. This means consideration of industrial standards regarding safety regulations for using such system in the assembly environment is required. This might include the use of safety fences and therefore it is important to investigate the applicability of virtual and solid fences. As the operators' safety is core in the assembly environment, it is most likely that this solution would require separate robot cells equipped with laser sensors that alerts and shutdown the system if human come close to the cell. The concept design presented in Figure 53 where the workstation is dedicated for riveting and screwing could be suitable.

In this solution, consideration is also needed with regard to the speed of the system because its implementation in the main line could affect the balancing of the workstations. However, the balancing of the workstation is not included in this study but needs to be considered in a separate study. In order to safe time it could be suitable to operate the tools in parallel. In this regard, safety consideration is also needed which refers to if both tools could be hanged on the same rail crane and sequenced in a way that they do not collide.

5.8 Short term solution at VIP-cross member subassembly

Likewise, the short term solution at workstation 4, this solution also results in improved ergonomic conditions for the operator. However, it does not reduce all the amount of manual work done by the operator. It is important to point out that this solution focuses on finding better tools that the operator could use to perform the tasks as in the current system. The LoA_{mech} for a few of the tasks is improved by for instance providing the lifting tool to the operator to pick and place the components on the moveable fixture. The moveable fixture provides easy movement and rotation and also eliminates the need to lift the VIP-cross member to the carrier as done currently. As the movable fixture allows the operator to easily rotate it while fastening the rivets on both sides of the VIP-cross member, it thereby prevents the operator from handling the rivet tool during movement. However, delivering the fixture to the main line might require the operator to apply some force to push it. Striving to improve the ergonomic conditions for the operator also includes the placement of the material pallets at appropriate height according to the VASA model. Even though, the LoA_{mech} for the riveting task remains at level four, the handle designed and attached with the tool enables the operator to handle it in a better way and thereby improves the ergonomics. The control buttons on the handle are used to tilt the head of the tool and fasten the rivets. The implementation of the push button allows the operator to call and return the tool after fastening the rivets.

A significant improvement of the LoA_{info} is also achieved where proper instructions of using the lifting tool is now available but it is uncertain if the instructions would enforce the operator to use the tool. However, it is the responsibility of the production manager to ensure that the instructions are updated and followed. The television screen provided at the workstation is connected with MONT which tells the operator about the amount of rivets to fasten. Similarly, the arguments outlined in Chapter 5.6 about increasing the visibility of the operator while fastening the rivets also stand for this solution.

One possible root cause to the ergonomic issues identified at this workstation is that the operator neglects using the existing tool for picking and placing the components. Information about the lifting tool was highlighted during the workshop and therefore not included in the measurement phase. The fact that the operator neglects the tool could probably be due to that it does not help to execute the task as desired. Another perspective could be the production manager’s failure to highlight that the tool actually exists.

For this solution to be viable requires considering the following important limitations;

- Weight
- Safe regulations

- Costs
- Physical space

One of the important limitations worth considering is the weight of the rivet tool because it needs to be hanged above the workstation. However, discussion with engineers at GTO highlighted that it could be possible to have such solutions using a stronger structure. The weight issue also opens up the discussion about safety regulations. Towards this end, it is good for the company to look into industrial standards regarding safety. The cost factor is also important to consider which refers to the integration cost of the rivet tool with the rail crane and the MONT system. A possible assumption is that the current space available at the workstation could be enough to execute this solution. However, if more space is needed it would require changing the layout and other consideration needed here is that it should be closer to the delivery point.

5.9 Long term solution at VIP-cross member subassembly

Arguments outlined about the long term solution at workstation 4 presented in Chapter 5.7 that improved the ergonomic conditions and reduced the amount of manual work also stand for this solution. Significant raise of the LoA_{mech} and LoA_{info} is achieved which resulted in fulfilling the TfCs. Besides inserting rivets into the VIP-cross member, all the other tasks are now shifted to an automated system and the operator is also partly responsible for monitoring the assembly process. Further increase of the LoA_{info} by implementing advanced sensor and vision systems would totally shift control of the process over to the technology and thereby the need of the operator at this workstation is unnecessary.

The REBA score obtained for inserting the rivets into the VIP-cross member presented in Chapter 4.4 showed an ergonomic risk which was mainly because the operator had to bend while performing the task as the static fixture is not adjustable. However, in this case, the fixture is incorporated with the AGV and is adjustable which prevents the operator from bending while inserting the rivets.

It is worth pointing out that the daily production of the VIP-cross member is less than twenty pieces and therefore arguable whether solution of this kind is even needed at this subassembly line. A presumption is to order the VIP-cross member in a different way or outsource its assembly to an external supplier. However, this argument leads to shift the ergonomic issues identified in the measurement phase to the external supplier. Another argument to consider is whether the amount of rivets on the product could be reduced without changing its stability. This needs further discussion with the product designer to see its possibility.

The important limitations to consider in this case are similar to those mentioned in Chapter 5.7 above. Some exceptions are that less consideration is needed for flexibility and speed. This is because the product is standardized and as mentioned the volume required per day is low. The product is only assembled when needed in the main line and there is no time constraint regarding the cycle time.

5.10 Variation handled by operator 3 at workstation 4

Each conceptual solution proposed for operator 3 at workstation 4 is designed keeping in mind the variation handled by that operator which is presented in Chapter 4.2. The reach of the Jib crane in the short term solution is defined so that it satisfies the difference in wheelbase length between the shortest and longest truck variant. Similarly, the difference in the wheelbase length could also be taken care of by placing the crane at appropriate spot at the workstation. This will also shorten the distance that the operator has to cover in order to perform the assigned tasks. Moreover, the control buttons on the handle helps the operator to tilt the rivet tool at different angles thereby reaching the exact position of each rivet. As previously mentioned in Chapter 5.6, maneuvering the tool using the control buttons might increase the time it takes to fasten the rivets but this remains to evaluate in other studies related to cycle time or balancing. However, from a theoretical point of view, the ergonomics has improved for fastening the rivets.

The rivet tool and screwing tool designed in the long term solution allows movement in x and z directions so that the tools reaches the exact position of the rivets and screws. Regarding this, the project members mentioned previously that the system engineers at GTO have been consulted who assured that the information systems at GTO could possibly suit viability of this solution.

The collaborative robot proposed for picking and carrying the V-STAY to the chassis has a reach of 1.8 meters. Presumably this reach should be enough if the robot is placed at suitable spot at the workstation.

5.11 Levels of automation

The decided current LoA presented in Chapter 4.6, Appendix O and P are mainly based on the project members' assumptions. After the current LoA was decided, they were adjusted through discussion with the project supervisor who has good knowledge about the LoA scales presented in Chapter 2.4. It is important to mention that discussion with automation engineers could have resulted in further adjustment of the current LoA and thereby increase their accuracy. However, due to unavailability of people in the field of automation at GTO, this was not done.

5.12 Square of possible improvement

It is arguable that the SoPI matrices presented in Chapter 4.7.2 do not seem to be as accurate as thought. Firstly, solutions on the highest levels on both scales are rarely achievable in assembly environments. It is argued to set level six as maximum on the LoA_{mech}. Secondly, though the short term solutions did not result in increasing the LoA_{mech} beyond the decided minimum level in the SoPIs, the ergonomic conditions for the operators is improved theoretically. The discussion is to set the minimum LoA_{mech} to level four instead.

5.13 Ethical aspects and Sustainable development

Several ethical aspects have been considered throughout this thesis. Prior to selecting the study areas, the production managers responsible for the truck chassis assembly line were informed about the goal of this thesis. This was done to acquire consent from the production managers. Additionally, the production managers were asked to inform the operators working in the truck chassis assembly line about the study in order to draw their awareness. In order to avoid deceiving the operators present in the truck chassis assembly line, the project members clearly stated the goal of this study on several occasions while interacting with them during the selection procedures and the measurements.

The selection of the study area included the semi-structured and structured interviews with the TLs in the truck chassis assembly line. TLs were chosen because they have the most working experience and were also available for an interview because their responsibility was mainly to monitor the assembly work. In order to respect the interviewees' privacy, their names have not been mentioned. Instead, they are referred to as TL. After interpretation of their answers, they were sent back to the TLs who gave their approval. This was done to minimize errors and misinterpretation of their responses. In order to avoid stress and discomfort for the operators working in the truck chassis assembly line, they were not interviewed. This was to respect the operators' time and to avoid unnecessary engagement with them as they are working under time pressure.

In order to avoid invasion of privacy and anonymity, the operators working in the study areas gave their permission before they were photographed and video recorded. Moreover, the operators voluntarily participated in the video recording and photographing, and they were not forced. The project members assured the participants that all the recorded videos, interview and survey answers will only be used for this thesis and not be published anywhere else. Additionally, the participants were provided with the right to withdraw from the study at any stage.

Generally, the conceptual solutions for each workstation have been designed with focus on sustainable development. The short term conceptual solutions focus on the wellbeing of the operators working in the assembly line as the proposed tools and equipment theoretically results in better ergonomics. It is assumed that the company could solve the problem of high worker turnover as a result of the less ergonomic issues. The tools and equipment have been designed so that any operator can handle them with ease disregarding the age or gender. The solutions also propose proper work instructions which help the operators during decision making. Moreover, the short term conceptual solutions are assumed to be cost effective because their implementation does not require major changes in the system.

The implementation of the automatic system proposed in the long term conceptual solutions also improves the ergonomics, but might be very costly. Other consequences associated with the long term conceptual solutions are that they might result in the situation where the operators lose their jobs because almost all the tasks are carried out automatically.

It remains to see the impact of the conceptual solutions on the environment because the results are only theoretical. Assessing the environmental aspects of the solutions would be possible after further study and implementation in the assembly line. However, this is outside the scope of this thesis.

5.14 Suggestion for future studies

It remains to see how the Dynamo++ methodology would impact the results obtained if it would have been carried out iteratively involving more people especially from the production department and the operators themselves. However, as mentioned earlier, due to limited time and unavailability of production personnel, the methodology was not applied more than once.

The GTO pilot plant located in the Tuve plant would be a good resource for the verification and implementation of the suggested solutions. If they prove to be suitable it is advised to change the current way of working accordingly. GTO can use the Dynamo++ methodology progressively in other parts of the assembly line to accomplish similar goals as of this thesis. Additionally, GTO could try to evaluate the methodology using other TfC.

For the future application of the Dynamo++ methodology, it is important that GTO strive towards having a standardized way of working. The current state measurement findings showed that the operators in the truck chassis assembly line perform the assigned tasks based on their experiences. This way of working could be attributed to the lack of proper work instructions. Strive towards a standardized way of working will ease the continuous improvement of the tools and equipment using the Dynamo++ methodology.

5.15 Reliability and validity

Theoretically, the measurement findings and the generated conceptual solutions in this thesis are validated through discussions with the project examiner and supervisor at Chalmers as well as the engineers at GTO. However, all the conceptual solutions proposed are yet to be physically validated and no guarantee can be made that they will solve the identified problems in the current system. This is because no actual testing and implementation in the assembly environment have been carried out.

In order to gather the opinions of the higher management and the operators about the conceptual solutions, they were presented at two separate meetings held at GTO headquarter and at the Tuve Plant. In general, the participants commented about the Dynamo++ methodology as a good tool that could help them through their journey towards an automated assembly line. Moreover, they also commented about the applicability of the conceptual solutions after exploring the mentioned limitations.

6 Conclusions

This chapter gives answer to the research question and concludes the findings and discussion.

6.1 Answering the Research question

In this study, the RQ concerns whether a scientific methodology is effective to improve the LoA in the selected study areas. In this regard, the Dynamo++ methodology was chosen and evaluated which showed that it is applicable for successively increasing the LoA in the selected workstations. Measurement findings after applying the Dynamo++ methodology in the current system conclude improper handling of heavy tools and components. REBA assessment of the operators' postures resulted in high scores which indicate that the operators face high risk for injury and that change is needed. The analysis of perceived pain performed on the operators while they handle tools and components also received high scores which indicate concerns that need to be addressed. Moreover, there is lack of proper work instructions due to which the operators use their own experiences to perform assigned tasks. The findings also showed large variation in the manual work handled by operator 3 at workstation 4 while fastening rivets on different Reaction rods whereas the operator at the VIP-cross member subassembly line performs identical tasks because the product is standardized. Furthermore, measurement of the current LoA shows that all the tasks performed by both operators are located in the human assembling and monitoring area of the LoA matrix. Based on these measurement results, the methodology guided the project members to conduct the workshops where suitable tasks for improving the LoA were chosen, the SoPIs were designed and improvement suggestions were generated. During the workshop for generating improvement suggestions, difference of opinion between the higher management and the operators were found. The focus of the higher management is to completely automate the system whereas the operators want to carry out small improvements in the current system. In order to satisfy both, the suggestions are fitted in short and long term conceptual solutions for the selected operators. Finally, a detailed analysis of the suggestions generated conceptual solutions resulted in theoretically improving the system where most of the identified problems in the current system are solved.

The concept design in the short term solution for operator 3 at workstation 4 proposes investment in:

- Jib Crane
- Television screen

This solution improves the ergonomic conditions for the operator while fastening the rivets because the Jib crane allows better handling of the rivet tool. The amount of manual work is not reduced because the operator still performs all the tasks. The LoA_{mech} for fastening the rivets remains on level four as in the current system and the LoA_{info} is raised to level three. The LoA for the riveting task is improved from (4,1) to (4,3).

The long term conceptual solution for operator 3 at workstation 4 proposes following investments;

- Automated system for riveting
- Automated system for screwing
- Rail crane system
- FANUC Robot CR-35iA
- Material pallet with conveyor
- Screws threaded on both sides
- Silver colored rivets
- Information system
- Vision system

This solution fulfills both triggers for change because the amount of manual work is reduced and the ergonomic issues are solved as most of the tasks are shifted to the automated system. The LoA for fastening the rivets and picking the V-STAY are improved from (4,1) to (6,6). The LoA for tightening the screws is improved from (3,1) to (6,6). Guiding the robot to place the V-STAY into the chassis and inserting the screws into it are improved from (1,1) to (1,3).

The concept design at VIP-cross member subassembly line for the short term solution proposes investing in:

- Lifting tool
- Movable fixtures
- Rail crane
- Push button
- Television screen

This solution solves the ergonomic issues because better tools and equipment are provided to the operator. Some reduction in amount of manual work is achieved because shifting the VIP-cross member from the static fixture to the carrier is eliminated. The LoA for the riveting task is improved from (4,1) to (4,3) and for getting the components has improved from (1,1) to (4,3). The LoA for moving and rotating the fixture is at (3,3).

The concept design for the long term solution at VIP-cross member subassembly line proposes the following investments:

- AGVs
- FANUC Robot CR-35iA
- Silver colored rivets
- Rail crane
- Automated system for riveting
- Vision system

This solution fulfills both triggers for change because almost all the tasks are carried out by the automated system while the operator is only inserting the rivets and monitoring the system. The LoA for inserting the rivets remains at (1,1) while automatic positioning of the AGV is at (6,5). The LoA for getting the components is improved from (1,1) to (5,5) and for the riveting task has improved from (4,1) to (6,5).

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Appendix A: Selection process 1

Selection of the suitable study area was carried out in the assembly line for three days, which was based on observations, interviews, and survey answers. The observation procedure was carried out in the following order: Each workstation was observed twice and the observations were made by two different observers. Directly after each observation, the observers' findings were discussed before a final score was decided. The interviews consisted of structured, survey, and semi-structured interviews and the interviewees were only the team leaders (TL) responsible for each part of the Base module, See Appendix B for the interview questions and responses. The TLs were chosen because they had worked for long time and thereby has better understanding of the process. Moreover, interviewing each operator was difficult due to the time pressure on them.

Phase 1

The first selection phase, Figure 1, was based on observing all the areas in the assembly line. After the observation, the project members chose the Base module area for the study because their observations showed high variations between the different truck chassis assembled there and manual handling of heavy tools and components by the operators. Moreover, the stakeholders also showed their concerns regarding the Base module area. The reason behind was to make the situation better for the operators working there by improving the LoA.

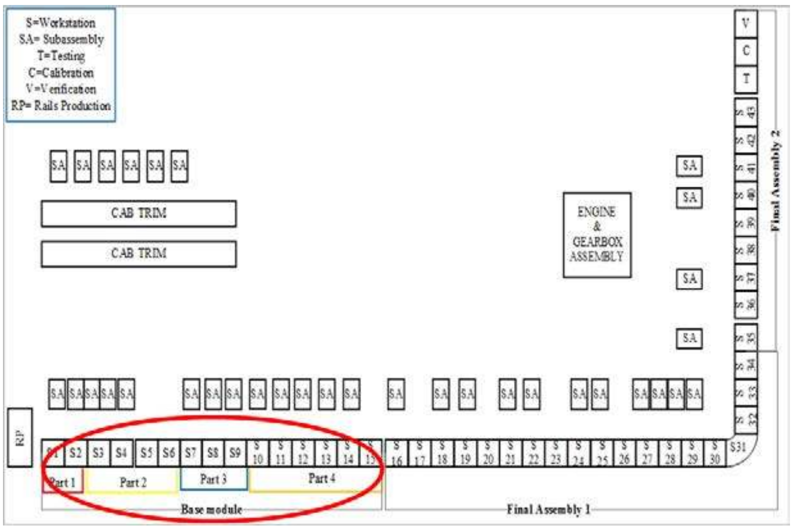


Figure 1: Selection phase 1

Phase 2

The Base Module is where the truck chassis is assembled and it is divided into four parts. Therefore, this selection phase was aimed to identify suitable part of the Base module for the study. The selection criteria for identifying suitable part was based on the project members' observations, survey answers filled by the TL responsible for each part, and interview answers given by each of them. Prior to this phase, the project members prepared statements, Figure 2, which was distributed to each TL who scored them according to the given scale, Figure 3. Thereafter, the project members also observed the different parts using the same statements and scored them. Finally, the TL for each part was interviewed to gather their opinions about ongoing activities in each part. See Appendix B for interview answers.

Figures 2 lists the statements used and the scores obtained for each part. The statements considered were ranked on a scale of 1 to 5, Figure 3, where 1 means that the consideration for increasing the LoA is not needed and 5 means that due to high critical condition consideration for improving the LoA is needed. The final scores in Figures 2 were set by interpreting the interview answers of the TLs, and by taking the mean of the project members' observations and the TLs survey scores. The results indicated that Part 2 is where the need to increase the LoA is most, Figure 4.

	Part 1			Part 2			Part 3			Part 4		
Statements	Observation	Survey	Final score	Observation	Survey	Final score	Observation	Survey	Final score	Observation	Survey	Final score
How many product variants are there	5	3	4	5	4	4.5	4	4	4	4	4	4
What is the frequency of same variant coming in line	5	3	4	5	3	4	4	4	4	4	4	4
Frequency of changes between variants	5	4	4.5	5	4	4.5	4	5	4.5	4	3	3.5
Available instructions suitable for workers	4	5	4.5	5	5	5	3	5	4	4	4	4
How many components to pick	5	5	5	5	5	5	3	4	3.5	4	3	3.5
Similarities between components	5	5	5	5	3	4	2	5	3.5	2	4	3
How is the handability of tools	3	4	3.5	5	5	5	4	3	3.5	3	5	4
Are fixtures suitable	3	4	3.5	5	2	3.5	3	2	2.5	4	2	3
Is positions of material racks suitable	4	3	3.5	4	5	4.5	3	4	3.5	4	4	4
Are workers facing time pressure	2	5	3.5	5	4	4.5	5	5	5	5	5	5
What is the competence level of the workers	2	3	2.5	4	4	4	3	5	4	3	5	4
How is the Ergonomics condition	4	4	4	5	4	4.5	4	4	4	5	5	5
How many tasks each worker has to do	5	3	4	5	3	4	3	3	3	3	4	3.5
If different tasks has effect on quality	4	5	4.5	5	4	4.5	4	5	4.5	3	4	3.5
Sum			56			61.5			53.5			54

Figure 2: Statements and scores for selection phase 2

Scores	
1	Very low critical condition, consideration not needed
2	Low critical condition, consider if required
3	Medium critical condition, consider
4	High critical condition, consideration needed
5	Very high critical condition, consideration needed

Figure 3: Interpretation of the scores

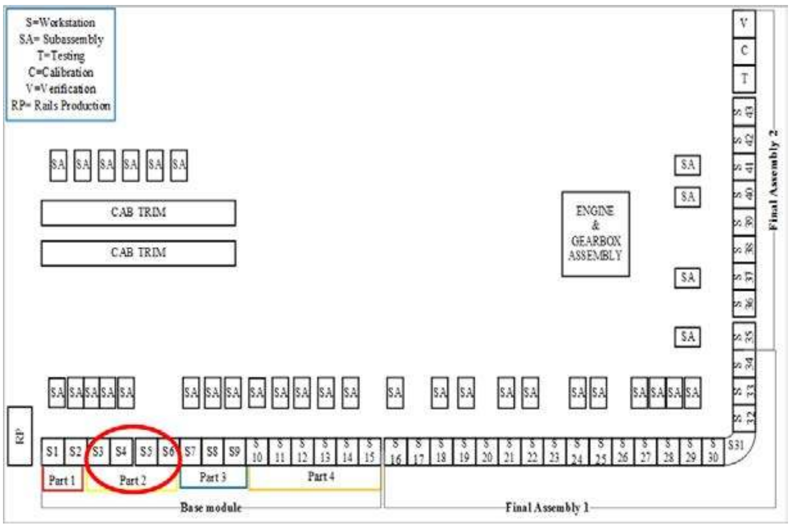


Figure 4: The result of selection phase 2 where part 2 of Base module is chosen

Phase 3

Selection phase 3 was aimed to identify workstation(s) in part 2 for the study. Part 2 of the Base module consists of workstations 3 to 6, Figure 5. The procedure for identifying suitable workstation(s) was based on the project members' observations and the survey answers from the TLs. Figure 5 illustrates the results obtained for each workstation of part 2. During phase 3, some of the statements used in phase 2 were combined and three factors were used for selecting the suitable workstation(s). Each factor was ranked on a scale of 1 to 3 where 1 stands for good and 3 stands for bad condition, see Figure 6. The final scores for each statement were set based on the scores obtained from the project members' observations and survey answers from the TL.

	Area 2											
	WorkStation 3			WorkStation 4			WorkStation 5			WorkStation 6		
Factors	Observation	Survey	Final score	Observation	Survey	Final score	Observation	Survey	Final score	Observation	Survey	Final score
Quality	2	1	2	1	2	2	3	3	3	3	3	3
Ergonomics	2	1	2	2	2	2	2	2	3	2	3	3
Instructions	2	2	3	2	2	3	3	2	3	3	2	3
Sum			7			7			9			9

Figure 5: Statements and scores obtained for each workstation in Part 2

Scores	
1	Good
2	Medium
3	Bad

Figure 6: Interpretation of the scores

Final selection of suitable workstation(s)

The findings of this selection procedure were presented at the first milestone meeting held on 2016-02-09 with stakeholders from GTO and Chalmers. The aim was to select the suitable workstation(s) in part 2 for the study. According to the results, Figure 5, workstation 5 and 6 received the highest scores. However, due to the stakeholders' concerns about the critical task of riveting at workstation 4, it was decided to further investigate that and select an operator for the study. Additionally, the decision was taken to examine the three sub-assembly lines associated with workstation 3 and select one of them to set an appropriate scope for the project, Figure 7.

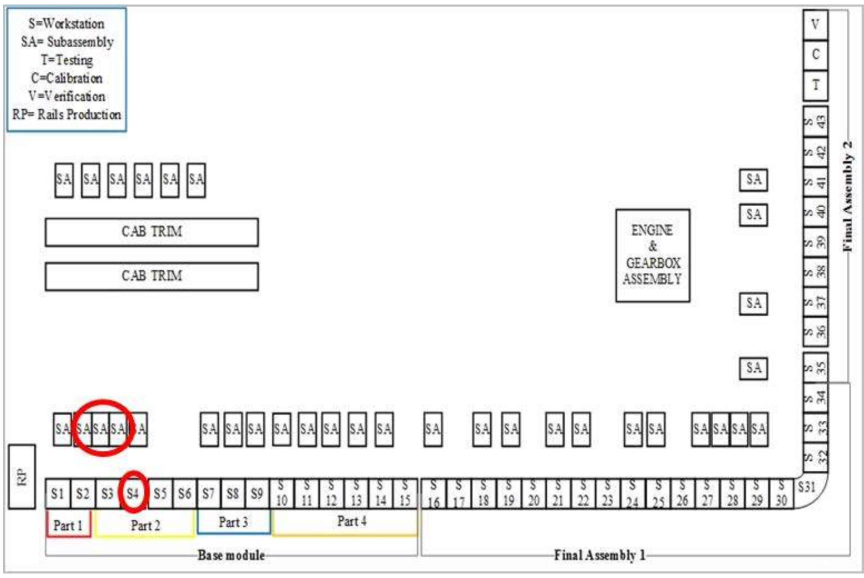


Figure 7: Result of Selection phase 3

Appendix B: Interviews with Team leaders

During the interviews the interviewees are referred to as team leaders (TL) and their responses were directly written down. After the interviews, the TL responses were interpreted by looking for problems faced by the operators at each part of the Base Module. After the interpretation of the TLs' responses, it was send back to them for their approval. The semi-structured interviews were based on the following questions:

- What is your opinion regarding the tasks carried out in your part?
- What are the difficulties faced in this part?
- Which are the most time consuming tasks in this part?

Interview with TL – Part 1: Workstations 1-2

According to the TL, the main responsibilities in this area are placing the side rails on the AGV, placement of the cross members and subassemblies in the chassis. According to the TL, the tools used by the operators in this part are large in size. The TL stated that transporting the subassemblies and cross member using airlifts includes high ergonomic risks. The TL explained, "Operators have to push the heavy components at the desired locations and this require them to use both hands to hold the component and simultaneously operate the tool". The TL concluded that this leads to the operator standing in abnormal postures. The TL stated, "As a result the operators can face injuries in their shoulders and hands". The TL further stated, "All the tasks are repetitive which result in the operator worn out their body". The TL explained that they experienced low quality in this area because there are a lot of tasks to handle. The TL stated, "The balancing has been done in such a way that the operators have to rotate between many different tasks". The TL further explained that special variants take the most time due to differences in components and concluded, "The more rotation between the operators, the higher risks that quality reduces".

Interview with TL – Part 2: Workstations 3-6

According to the TL, most of the tasks carried out in this area are to assemble heavy components such as cross-members, axle holders and consoles. One of the most important tasks is riveting because it gives good stability to the chassis compared with the screws. The amount of rivets varies between the different variants. According to the TL, the riveting operation is critical because if done improperly could require after adjustment. "Often we realize that the riveting has been done wrongly late in the assembly process and we have to disassemble the chassis completely in order to do the adjustments which is time consuming and costly". Regarding the riveting tool, the TL expressed concerns that it is not ergonomically suited for the operators because it is large in size and requires the operator standing in abnormal postures while using it. Additionally, the TL stated that other tools e.g. airlifts, screwing equipment etc. also have risks of operators getting injured. The TL exemplified that lifting tools among others are not safe because there is risk that the operators pinch in their hands. "In this area there is always new assembly information coming in most of the time and operators have to keep track of a lot of tools and components which increases the risk of making mistakes". The TL further stated that handling of the rivet tool also has the risks for nerve injuries. "There are large product variants, for instance, the same model can consist of different components". "Paper instruction is used which requires operators to remember the tasks". However, the TL mentioned that operators often neglect reading the instructions in order to keep up with the cycle time. The TL explained that quality is a problem because the operators have to carry out many different tasks. “The larger the area the operator has to work with, the more risks for them to miss something”.

Interview with TL – Part 3: Workstations 7-9
According to the TL, this area is dedicated to tightening all M14 screws on the chassis and start of wiring. “The most ergonomic risk is that the operators have to bend their back while screwing”. Moreover, vibration in the tools induces risks for hand, shoulder and injuries in other body parts. “It occurred that shorter operators sometimes got thrown away due to the high force used when screwing”. The TL mentioned that operating the tools after few times (e.g. 8 hours) leads to pain in the wrists. The TL judged that tightening screws on the outer side of the base model is ergonomically suitable. “The most risks are when operators have to carry out screwing inside the chassis which requires that they have to bend heavily resulting in abnormal postures”.

Interview with TL – Part 4: Workstations 10-15
According to the TL, this area is responsible for all the wiring tasks which includes installation of all pneumatic devices e.g. air tanks, electronics, cabling and pneumatic tubes. The TL mentioned that the most risks is due to heavy bending as the operators mount the cables and tubes. The TL stated, “Each bundle of cable weighs approximately 6-10 kilograms and the operators have to carry the bundle during mounting”. “The most tasks are carried out using hands which results in that the operators pinch in their hands”. The most common tool used according to the TL is hand pistol for cutting the clippers used to tighten the cables and tubes on the chassis. The TL mentioned that the operators experience pain in their hands after few hours of using the hand pistol. Due to high variation between the tubes, the TL mentioned that it is difficult for the operators to keep track of the positions to mount them.

Appendix C: Selection process 2

This selection procedure was aimed to select an operator doing riveting at workstation 4 and also to choose one of the subassembly lines associated with workstation 3. The selection procedure was based on the TfCs which are;

- To reduce the amount of manual work performed by the operators and,
- To improve the ergonomics for each operator

Figure 1 illustrates the Base module and the subassembly lines associated with workstation 3. Three operators are working with kitting, the subassembly of the engine cross member and front cross member on rotational basis. A single operator is working at the VIP-cross member subassembly line where the components used for the VIP-cross member are placed in the material pallets at the workstation. Workstation 4, Figure 2, consists of four operators responsible for riveting and performing other tasks on the truck chassis.

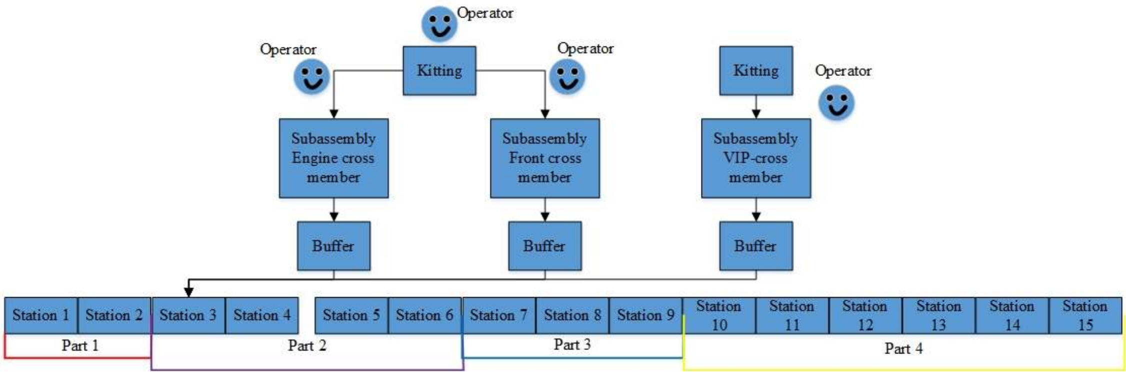


Figure 1: Layout of the Base module and subassemblies associated with workstation 3

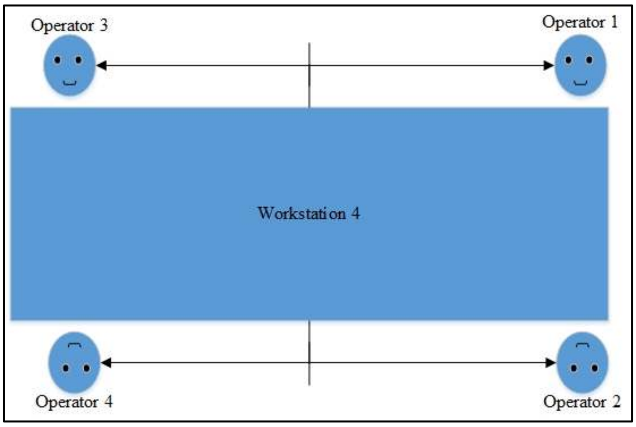


Figure 2: Workstation 4 of the truck chassis assembly line

Table 1 lists the main tasks carried out by the operators at workstation 4. It is observed that operators 1 and 2 are doing approximately similar tasks and therefore they have been considered as single operator. It can also be seen that operators 3 and 4 are doing identical riveting tasks but difference was placing and tightening the V-STAY.

For assessing the manual work, SPRINT was used for the operators doing the riveting tasks.

Table 1: Tasks carried out by the operators at workstation 4

Station 4					
	Operator 1	Operator 2		Operator 3	Operator 4
Tasks	Number of tasks	Number of tasks	Tasks	Number of tasks	Number of tasks
Rivet engine cross member	2	2	Unlock fixture arm	1	1
Change rivet tool head	1	1	Rivet T-Ride (Reaction Rod)	12	12
Rivet front stabilizer	2	2	Rivet cross member axle arrangement	4	4
Rivet rear front spring hanger	2	2	Rivet cross member axle arrangement	4	4
Rivet Gearbox cross member	4	4	Place V-STAG	2	
Remove screw	1	1	Insert Screws V-STAG	4	4
Insert screws gearbox cross member	14	16	Tighten screws V-STAG		8
Insert screws reinforcement consoles	2				
Insert screws battery box		6			
Tighten M8 screws	2				
Insert screws fusebox		6			
Insert screws Fuel tank	15	10			

Table 2 lists the tasks carried out by the kitting operators for the engine cross member and front cross member subassembly lines.

Table 2: Tasks carried out by the kitting operators for the engine and front cross member subassembly lines

Kitting subassembly Engine Cross member (Motorbalk)		Kitting subassembly Front Cross member (Frambalk)	
Tasks	Number of tasks	Tasks	Number of tasks
Fastener suspensions	2	Get fixture	
Tighten screws	6	Get left side component	1
Rubber pillows	28	Get right side component	1
Console left	5	Get front component	1
Console right	5	Get upper left component	1
Console middle	3	Get upper right component	1
Riveting	8	Pick Screws and washers	2
Screwing	8	Insert screws and washer	2
Deliver to subassembly		Deliver to pre-assembly	

Table 3 lists the tasks carried out by the operators responsible for the subassembly of the engine cross members, front cross member and the VIP-cross member. The components needed for assembly of the VIP-cross member are kitted by the same operator responsible for its assembly.

Table 3: Tasks for assembly of engine cross member, front cross member and VIP-cross member

Subassembly Engine Cross member		Subassembly Front cross member		Subassembly VIP-balk	
Tasks	Number of tasks	Tasks	Number of tasks	Tasks	Number of tasks
Tighten screws	4	Get & Insert screws and washer right side	7	Get and place left component	1
Rivet	8	Get & Insert screws and washer left side	7	Get and place right component	1
Get and insert screws, nuts, and washers	8	Attach console for cooler system	4	Get and place middle component	1
Tighten screws, nuts, and washers	8	Attach pinnbultar till multibracket	2	Get and insert rivets	10
Get and insert screws and nuts	2	O-ring coh sexkantsmuttrar	4	Do rivet	10
Get and attach consoles	3	Side console lower front	6	Place component in rack	1
Tighten consoles	3	Delivery to station 3		Deliver rack to station 3	
Deliver to station 3					

The next step of this selection process is to ergonomically assess the operators. For the ergonomics analysis, only operators 1 and 3 at workstation 4 were considered. Operators 3 and 4 as seen in Table 1, are doing identical riveting tasks but differs while mounting the V-STAY. The project members' observation showed that inserting the V-STAY is most critical than screwing it and therefore operator 3 was assessed ergonomically. Moreover, the operators working in the subassembly lines were considered. Ergonomic analysis of the operators responsible for the kitting tasks at each subassembly line has not been carried out as the tasks are approximately identical. The kitting operation for the selected subassembly will be considered during the study. That is, if subassembly for the engine cross member will be selected, the kitting operation associated with it will also be studied.

Ergonomic analysis

Assessment of the operators' postures while performing critical tasks at workstation 4 and the subassembly lines have been carried out using REBA (Rapid Entire Body Assessment). REBA is a tool that analyses the operators' entire body structure when performing tasks (Berlin & Adam, 2014). A REBA score sheet was used to assess the different tasks performed by the operators where high scores indicate higher ergonomic risks. A REBA score sheet was used during the assessment and then the scores were transferred into the tables. See Appendix D for the REBA score sheet.

Figure 3-7 illustrates the operators' postures that were assessed. Table 4 and Table 5 contain the REBA scores obtained for operator 1 and 3 and the operators at the subassembly lines.

Operator 1 at workstation 4

Figure 3: a) Riveting vertical b) Riveting horizontal c) Grabbing riveting tool

Operator 3 at workstation 4

Figure 4: a) Horizontal riveting b) Grabbing tool c) Inserting V-STAY d) Screwing

Engine cross member subassembly line

Figure 5: a) Grabbing riveting tool b) Horizontal riveting c) Screwing

Front cross member subassembly line

Figure 6: a) Reaching for tool b) Horizontal screwing c) Vertical screwing

VIP-cross member subassembly line

Figure 7: a) Get component b) Getting rivet tool c) Horizontal riveting d) placing subassembly

Final selection of the operator and the subassembly line

The findings of this selection procedure were presented at a second milestones meeting held on 2016/16/02 which involved stakeholders from GTO and Chalmers. The aim of the meeting was to select an operator at workstation 4 and one of the subassembly lines for the study.

Figure 8 illustrates the final result of selection process 2. Base on the findings, Table 1, the decision was made to select operator 3 at workstation 4 because the number of critical tasks performed by that operator are more than that of operator 1. Moreover, REBA scores listed in Table 4 showed that operator 3 faces higher risks than operator 1 while inserting the V-STAY. Furthermore, the large product variation that operator 3 has to handle will be considered during the study.

The subassembly line responsible to assemble the VIP-cross member was chosen based on the REBA scores, and to balance the workload because the study will consider the large product variation handled by operator 3. At this subassembly line, only the standardized components are assembled.

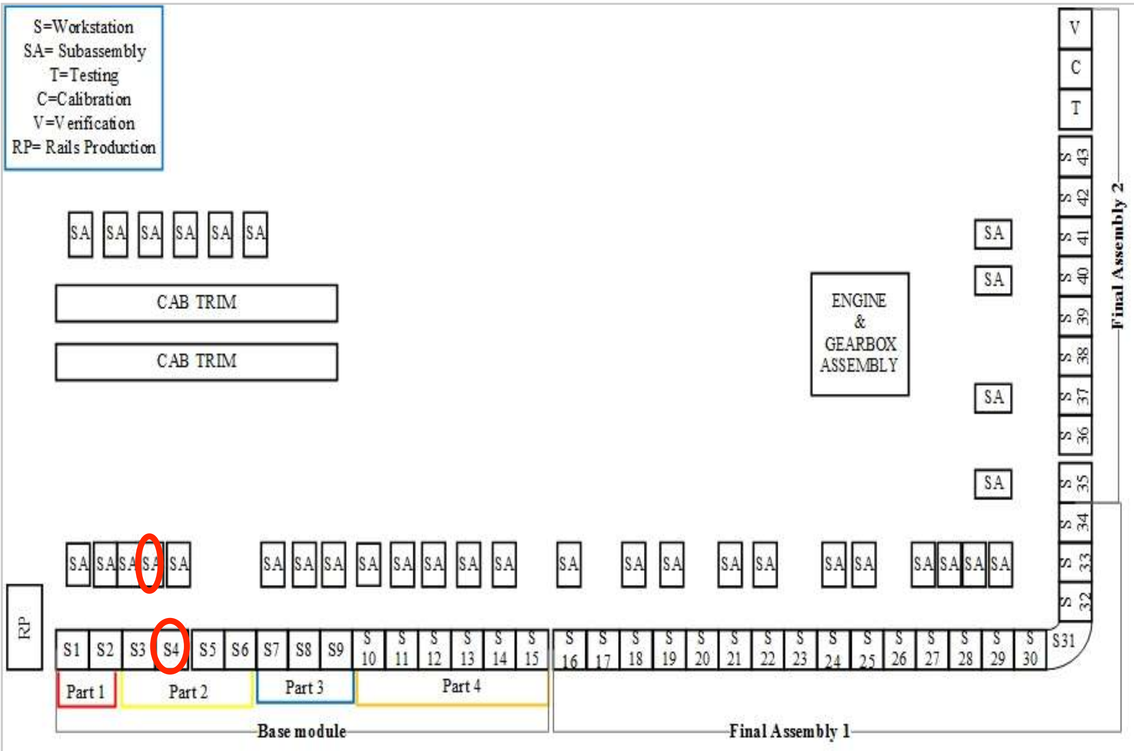


Figure 8: The final result of selection process 2 where operator 3 at workstation 4 and the operator at the VIP-cross member subassembly line are chosen for the study

REBA scores for selection process 2

Table 4: REBA scores for operator 1 and 3 at workstation 4

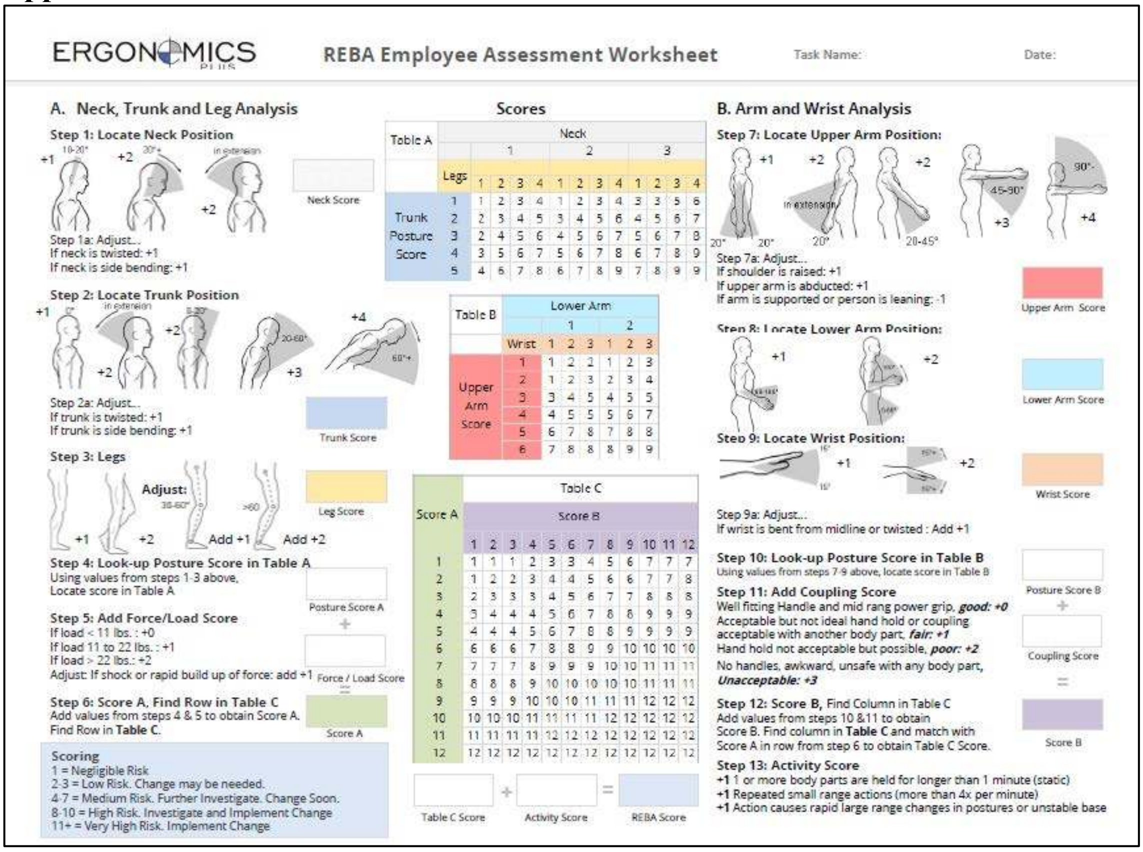
	Operator 1			Operator 3			
Tasks	Reviting horizontal	Grabbing reviting tool	Vertical Reviting	Screwing	Grabbing reviting tool	Inserting V-Stag	Horizontal Reviting
Neck score	2	2	3	3	2	3	2
Truck score	2	3	3	5	3	5	2
Legs score	2	2	2	2	2	2	2
Table A score	4	5	6	8	5	8	4
Force/Load score	3	3	3	2	2	1	2
Score A	7	8	9	10	7	9	7
Upper arm score	4	3	3	3	4	4	5
Lower arm score	2	2	2	2	2	2	2
Wrist score	2	2	2	2	2	2	2
Table B score	6	5	5	5	6	6	8
Coupling score	2	2	2	1	2	2	2
Score B	8	7	7	6	8	8	10
Table C score	10	10	11	11	10	11	11
Activity score	3	2	3	2	2	2	3
REBA score	**13**	**12**	**14**	**13**	**12**	**13**	**14**

Table 5: REBA scores for the three subassembly lines associated with workstation 3

	Subassembly Engine cross member			Subassembly VIP-balk			
Tasks	Screwing	Grabbing reviting tool	Horizontal Reviting	Getting component	Getting reviting tool	Placing subassembly	Horizontal Reviting
Neck score	2	2	3	1	1	1	3
Truck score	1	2	3	4	2	2	3
Legs score	1	2	3	2	1	1	2
Table A score	1	4	7	5	2	2	6
Force/Load score	1	2	3	2	2	1	3
Score A	2	6	10	7	4	3	9
Upper arm score	4	5	3	2	5	3	4
Lower arm score	1	2	1	1	2	1	2
Wrist score	2	2	2	2	2	2	2
Table B score	5	8	4	2	8	4	6
Coupling score	1	2	2	2	2	1	2
Score B	6	10	6	4	10	5	8
Table C score	4	10	11	8	9	4	11
Activity score	1	2	3	1	2	1	3
REBA score	**5**	**12**	**14**	**9**	**11**	**5**	**14**

	Subassembly front cross member		
Tasks	Horizontal Screwing	Vertical screwing	Reaching for tool
Neck score	1	1	2
Truck score	1	1	2
Legs score	1	1	2
Table A score	1	1	4
Force/Load score	1	1	0
Score A	2	2	4
Upper arm score	2	5	5
Lower arm score	1	2	1
Wrist score	2	2	1
Table B score	2	8	6
Coupling score	0	1	1
Score B	2	9	7
Table C score	2	6	7
Activity score	1	1	0
REBA score	**3**	**7**	**7**

Appendix D: REBA assessment worksheet



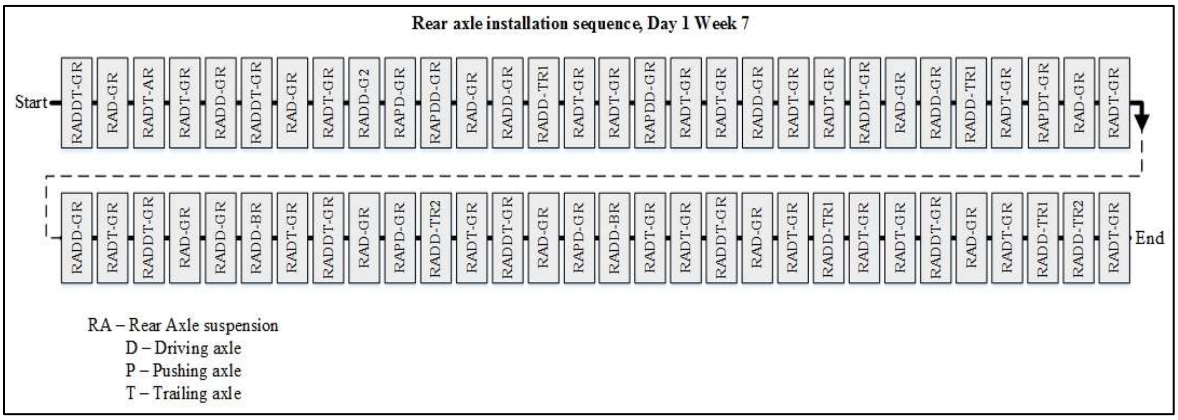
Appendix E: Rear axle installation for two weeks

	Week 7					Week 8				
Truck Variant	Day 1	Day 2	Day 3	Day 4		Day 1	Day 2	Day 3	Day 4	Day 5
RADD-TR2	2	5	4	2		0	4	3	3	2
RADD-BR	2	2	5	7		6	6	5	1	4
RAPDT-GR	1	0	2	2		0	0	3	1	2
RADD-TR1	4	6	2	0		2	1	2	1	1
RAPDD-GR	2	2	0	0		1	1	1	0	0
RAPD-GR	3	2	4	4		5	5	4	11	10
RADD-G2	1	0	0	0		5	4	2	0	0
RADD-GR	6	7	7	3		3	6	5	6	8
RADT-GR	20	17	18	22		18	14	18	15	16
RADT-AR	1	0	0	0		0	0	0	0	0
RAD-GR	10	9	8	7		8	8	7	7	8
RADDT-GR	8	9	9	7		9	10	7	10	6
RADDT-G2	0	0	1	1		1	1	1	0	3
RAD-L90	0	0	0	0		2	0	0	0	0
RAD-G2	0	0	0	0		0	0	2	0	0
Total	60	59	60	55		60	60	60	55	60

Percentages rear axle installation for two weeks

	Week 7					Week 8				
Truck Variant	DAY 1	DAY 2	DAY 3	DAY 4		DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
RADD-TR2	0.03	0.08	0.07	0.04		0.00	0.07	0.05	0.05	0.03
RADD-BR	0.03	0.03	0.08	0.13		0.10	0.10	0.08	0.02	0.07
RAPDT-GR	0.02	0.00	0.03	0.04		0.00	0.00	0.05	0.02	0.03
RADD-TR1	0.07	0.10	0.03	0.00		0.03	0.02	0.03	0.02	0.02
RAPDD-GR	0.03	0.03	0.00	0.00		0.02	0.02	0.02	0.00	0.00
RAPD-GR	0.05	0.03	0.07	0.07		0.08	0.08	0.07	0.20	0.17
RADD-G2	0.02	0.00	0.00	0.00		0.08	0.07	0.03	0.00	0.00
RADD-GR	0.10	0.12	0.12	0.05		0.05	0.10	0.08	0.11	0.13
RADT-GR	0.33	0.29	0.30	0.40		0.30	0.23	0.30	0.27	0.27
RADT-AR	0.02	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
RAD-GR	0.17	0.15	0.13	0.13		0.13	0.13	0.12	0.13	0.13
RADDT-GR	0.13	0.15	0.15	0.13		0.15	0.17	0.12	0.18	0.10
RADDT-G2	0.00	0.00	0.02	0.02		0.02	0.02	0.02	0.00	0.05
RAD-L90	0.00	0.00	0.00	0.00		0.03	0.00	0.00	0.00	0.00
RAD-G2	0.00	0.00	0.00	0.00		0.00	0.00	0.03	0.00	0.00

Appendix F: Rear axle installation sequence for Day 1 Week 7



Appendix G: Data table for workload for week 7 and 8

Rear Axle Suspension variants	Average Workload (min)
RADD-G2	5,0315
RADD-BR	6,233
RADD-GR	5,8218
RADDT-G2	4,701
RADDT-GR	5,439
RADD-TR1	6,3756
RADD-TR2	6,1337
RAD-G2	4,337
RAD-GR	4,685
RAD-L90	4,218
RADT-GR	5,8538
RAPDD-GR	5,324
RAPD-GR	4,685
RAPDT-GR	5,752

Appendix H: Data table for wheelbase lengths for week 7 and 8

Suspension Type	Wheel base																			
	3000	3200	3300	3400	3500	3600	3700	3800	3900	4100	4300	4350	4600	4800	4900	5100	5200	5600	6000	6400
RAD-G2											2									
RAD-L90											1				1					
RAD-GR			10		10		19	21			1						3	8		
RADD-BR		2											4		2	19	2	2		7
RADT-GR	14	16		39	1		1		10		9		12	17	14	3	3	6	13	
RADD-GR	4	10		8					2		1		10		1	5	1	5	4	
RADD-TR1				2		1			1				3		2	2		8		
RADD-TR2		4				5	1		8				8		3	1		1		
RADD-G2		1		8		1			1						1					
RAPD-GR									9	39										
RADDT-GR		1		2			27		9	2	10	1	7		2	2		12		
RAPDT-GR															3	4		4		
RADDT-G2		1		5			2			1										
RAPDD-GR						1			2				4							
RADT-AR											1									
Total	18	35	10	64	11	8	50	21	42	42	25	1	48	17	29	36	9	46	17	7

Appendix I: Glossary


a

b

c

d

e

f


g

h

i

j

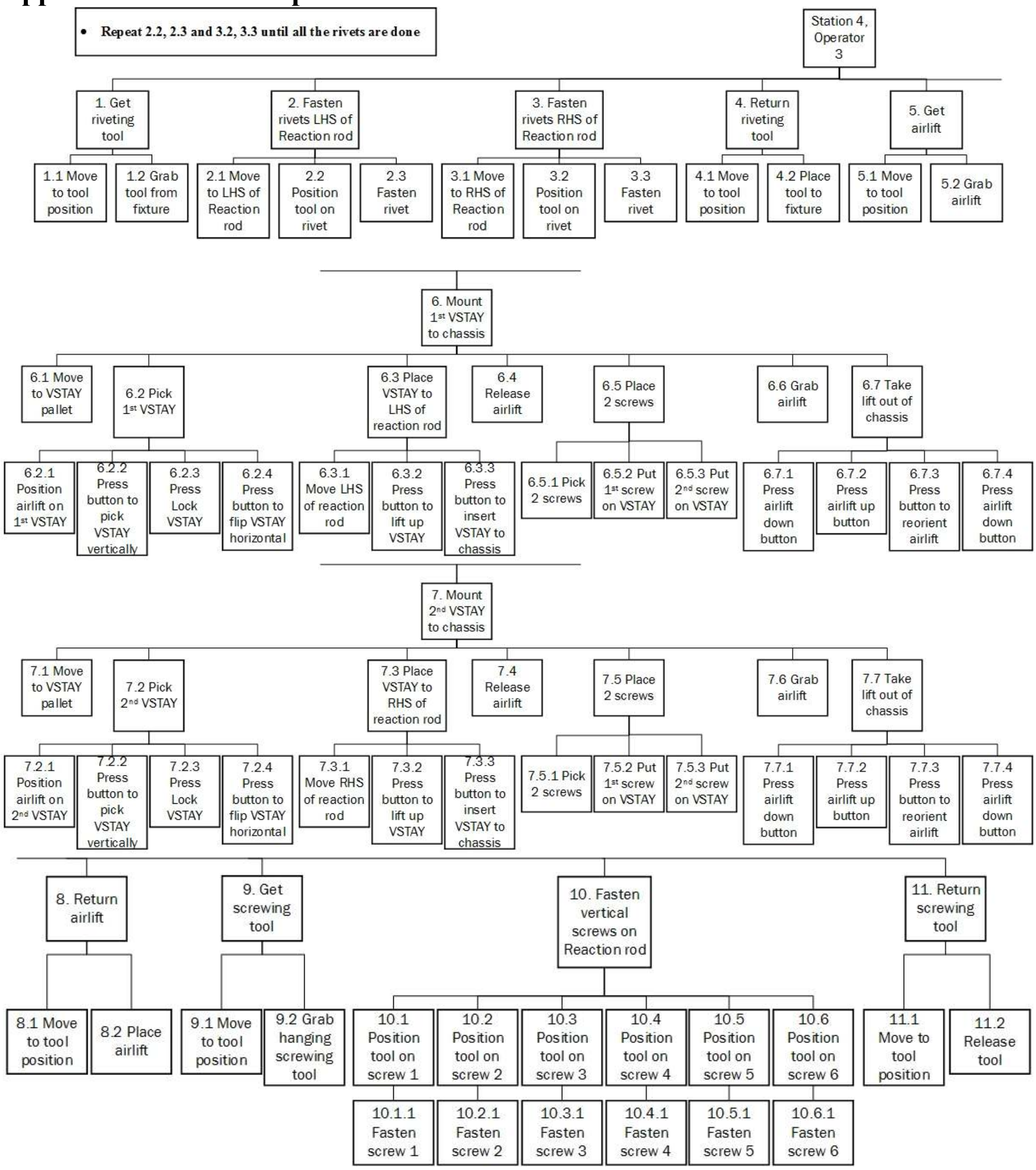

k

l

m

Component	Name	Weight (kilogram)
a	V-STAY	Circa 25
b	Cross member	Circa 10
c	Anchorage VIP	Circa 5
d	Anchorage cross	Circa 14
e	Screw M20*110	Not available
f	Screw M16*70	Not available
g,h.i.j.k,l,m	Reaction Rods	Not available

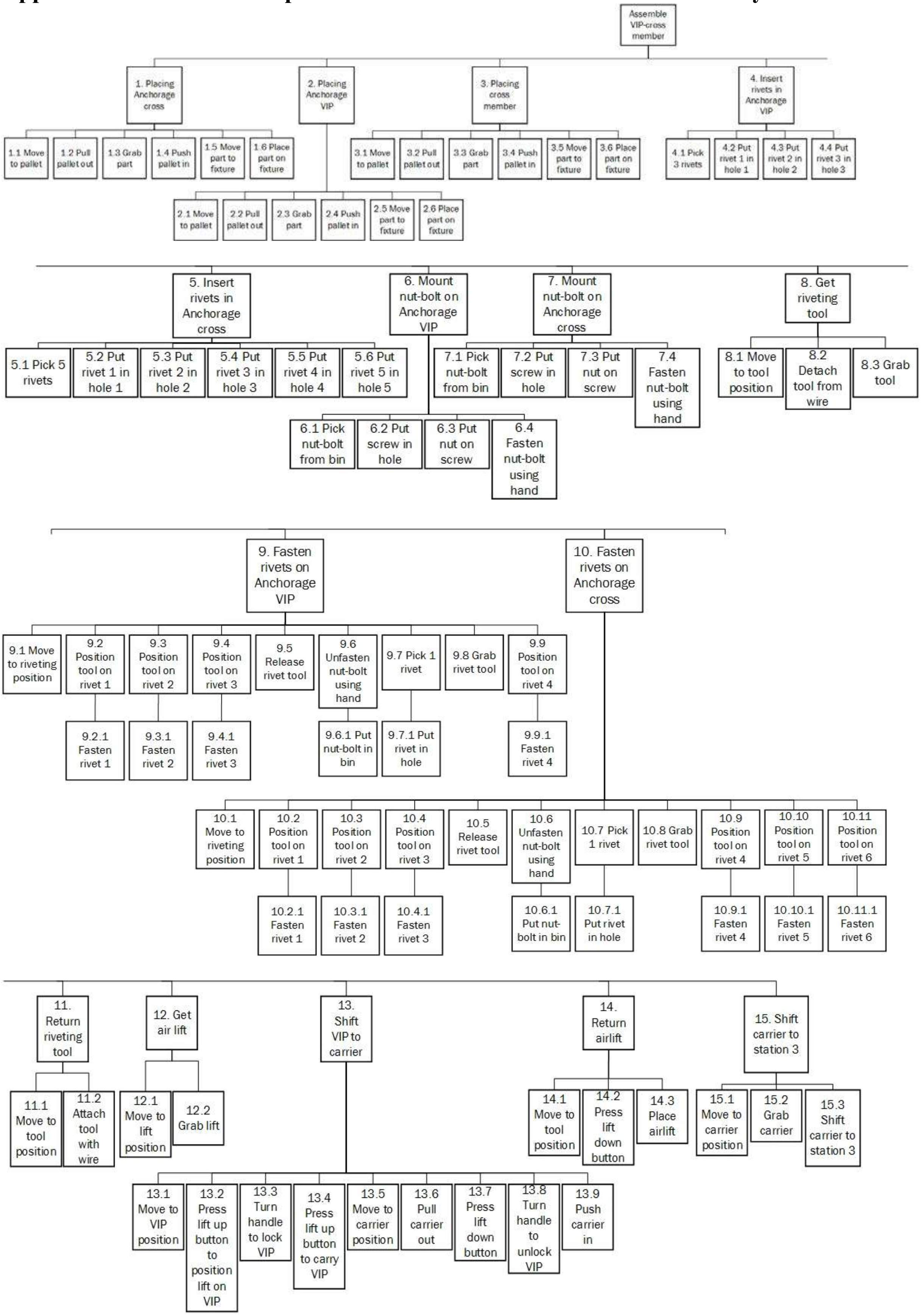
Appendix J: HTA for operator 3 at workstation 4



Appendix K: REBA scores for operator 3 at workstation 4

Operator 3 at wotkstation 4					
Tasks	Inserting V-STAG	Grabbing reviting tool	Horizontal Reviting	Vertical screwing	Reaching tool
Neck score	3	2	2	3	2
Truck score	4	1	2	3	1
Legs score	2	2	2	1	2
Table A score	7	2	4	5	2
Force/Load score	0	3	3	1	0
Score A	7	5	7	6	2
Upper arm score	4	5	4	5	5
Lower arm score	1	1	2	2	1
Wrist score	2	2	1	1	1
Table B score	5	7	5	7	6
Coupling score	0	2	2	0	1
Score B	5	9	7	7	7
Table C score	9	9	9	9	5
Activity score	1	1	2	0	1
REBA score	**10**	**10**	**11**	**9**	**6**

Appendix L: HTA for the operator at the VIP-cross member subassembly



Appendix M: REBA scores for the operator at the VIP-cross member subassembly line

Operator at VIP-balk subassembly line						
Tasks	Getting component	Grabbing reviting tool	Horizontal Reviting	Placing subassembly	Inserting revits	Multi-tasks
Neck score	1	2	3	1	3	2
Truck score	3	2	2	1	3	4
Legs score	2	2	1	1	1	1
Table A score	4	4	4	1	5	5
Force/Load score	0	2	3	1	0	2
Score A	4	6	7	2	5	7
Upper arm score	3	2	4	3	3	4
Lower arm score	1	2	2	1	1	2
Wrist score	1	1	1	2	2	2
Table B score	3	2	5	4	4	6
Coupling score	0	2	2	1	1	2
Score B	3	4	7	5	5	8
Table C score	4	7	9	4	6	10
Activity score	1	1	1	1	0	0
REBA score	**5**	**8**	**10**	**5**	**6**	**10**

Appendix N: Analysis of perceived pain

Information used in AviX Ergo for operator 3 at workstation 4

Operator 3 at workstation 4	
Total riveting operations on reaction rod	14
Total riveting operations on cross members	12
Total vertical screwing operations	6
Amount of V-Stag to insert in chassis	2
Total screwing operations on V-Stag	4

Information used in AviX Ergo for the operator at the VIP-cross member subassembly Line

Operator at VIP_balk subassembly line	
VIP-balk assembled per working day	15
Components to pick per VIP-balk (Anchorage VIP 5kg, Cross member 10.13kg, Anchorage cross 13.89kg)	3
Total amount of components to pick: 15x3	45
Rivets per VIP-balk	10
Total riveting operations: 15x10	150
Grabbing and returning riveting tool	30
Screws per VIP-balk	2
Total screwing and unscrewing operations per working day: 15x4	60

Appendix O: LoA tables for operator 3 at workstation 4

	Operations			Operations	
LoAmech	1.1	1.2	**LoAinfo**	1.1	1.2
7			7		
6			6		
5			5		
4			4		
3			3		
2			2		
1	x	x	1	x	x

	Operations				Operations		
LoAmech	2.1	2.2	2.3	**LoAinfo**	2.1	2.2	2.3
7				7			

6				6			
5				5			
4			x	4			
3	x	x		3			
2				2	x		
1				1		x	x

	Operations				Operations		
LoAmech	3.1	3.2	3.3	**LoAinfo**	3.1	3.2	3.3
7				7			
6				6			
5				5			
4			x	4			
3	x	x		3			
2				2	x		
1				1		x	x

	Operations			Operations	
LoAmech	4.1	4.2	**LoAinfo**	4.1	4.2
7			7		
6			6		
5			5		
4			4		
3	x		3		
2			2	x	
1		x	1		x

	Operations			Operations	
LoAmech	5.1	5.2	**LoAinfo**	5.1	5.2
7			7		
6			6		
5			5		
4			4		
3			3		
2			2		
1	x	x	1	x	x

	Operations and sub-operations																
LoAmech	6.1	6.2.1	6.2.2	6.2.3	6.2.4	6.3.1	6.3.2	6.3.3	6.4	6.5.1	6.5.2	6.5.3	6.6	6.7.1	6.7.2	6.7.3	6.7.4
7																	
6																	
5																	
4			x		x	x	x	x						x	x	x	x
3																	
2																	
1	x	x		x					x	x	x	x	x				
	Operations and sub-operations																

LoAinfo	6.1	6.2.1	6.2.2	6.2.3	6.2.4	6.3.1	6.3.2	6.3.3	6.4	6.5.1	6.5.2	6.5.3	6.6	6.7.1	6.7.2	6.7.3	6.7.4
7																	
6																	
5																	
4																	
3																	
2	x																
1		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	Operations and sub-operations																
LoAmech	7.1	7.2.1	7.2.2	7.2.3	7.2.4	7.3.1	7.3.2	7.3.3	7.4	7.5.1	7.5.2	7.5.3	7.6	7.7.1	7.7.2	7.7.3	7.7.4
7																	
6																	
5																	
4			x		x	x	x	x						x	x	x	x
3																	
2																	
1	x	x		x					x	x	x	x	x				

	Operations and sub-operations																
LoAinfo	7.1	7.2.1	7.2.2	7.2.3	7.2.4	7.3.1	7.3.2	7.3.3	7.4	7.5.1	7.5.2	7.5.3	7.6	7.7.1	7.7.2	7.7.3	7.7.4
7																	
6																	
5																	
4																	
3																	
2	x																
1		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	Operations	
LoAmech	8.1	8.2
7		
6		
5		
4		
3		
2		
1	x	x

	Operations	
LoAinfo	8.1	8.2
7		
6		
5		
4		
3		
2		
1	x	x

	Operations	
LoAmech	9.1	9.2
7		
6		
5		

	Operations	
LoAinfo	9.1	9.2
7		
6		
5		

4			4		
3			3		
2			2		
1	x	x	1	x	x

	Operations and sub-operations											
LoAmech	10.1	10.1.1	10.2	10.2.2	10.3	10.3.1	10.4	10.4.1	10.5	10.5.1	10.6	10.6.1
7												
6												
5												
4		x		x		x		x		x		x
3												
2												
1	x		x		x		x		x		x	
	Operations and sub-operations											
LoAinfo	10.1	10.1.1	10.2	10.2.2	10.3	10.3.1	10.4	10.4.1	10.5	10.5.1	10.6	10.6.1
7												
6												
5												
4												
3												
2												
1	x	x	x	x	x	x	x	x	x	x	x	x

	Operations			Operations	
LoAmech	11.1	11.2	**LoAinfo**	11.1	11.2
7			7		
6			6		
5			5		
4			4		
3			3		
2			2		
1	x	x	1	x	x

Appendix P: LoA tables for the operator at the VIP-cross member subassembly line

	Operations							Operations					
LoAmech	1.1	1.2	1.3	1.4	1.5	1.6	**LoAinfo**	1.1	1.2	1.3	1.4	1.5	1.6
7							7						
6							6						
5							5						
4							4						
3		x		x			3						

2							2						
1	x		x		x	x	1	x	x	x	x	x	x

	Operations							Operations					
LoAmech	2.1	2.2	2.3	2.4	2.5	2.6	**LoAinfo**	2.1	2.2	2.3	2.4	2.5	2.6
7							7						
6							6						
5							5						
4							4						
3		x		x			3						
2							2						
1	x		x		x	x	1	x	x	x	x	x	x

	Operations							Operations					
LoAmech	3.1	3.2	3.3	3.4	3.5	3.6	**LoAinfo**	3.1	3.2	3.3	3.4	3.5	3.6
7							7						
6							6						
5							5						
4							4						
3		x		x			3						
2							2						
1	x		x		x	x	1	x	x	x	x	x	x

	Operations					Operations			
LoAmech	4.1	4.2	4.3	4.4	**LoAinfo**	4.1	4.2	4.3	4.4
7					7				
6					6				
5					5				
4					4				
3					3				
2					2				
1	x	x	x	x	1	x	x	x	x

	Operations							Operations					
LoAmech	5.1	5.2	5.3	5.4	5.5	5.6	**LoAinfo**	5.1	5.2	5.3	5.4	5.5	5.6
7							7						
6							6						
5							5						
4							4						
3							3						
2							2						
1	x	x	x	x	x	x	1	x	x	x	x	x	x

	Operations					Operations			
LoAmech	6.1	6.2	6.3	6.4	**LoAinfo**	6.1	6.2	6.3	6.4
7					7				
6					6				
5					5				
4					4				
3					3				
2					2				
1	x	x	x	x	1	x	x	x	x

	Operations					Operations			
LoAmech	7.1	7.2	7.3	7.4	**LoAinfo**	7.1	7.2	7.3	7.4
7					7				
6					6				
5					5				
4					4				
3					3				
2					2				
1	x	x	x	x	1	x	x	x	x

	Operations				Operations		
LoAmech	8.1	8.2	8.3	**LoAinfo**	8.1	8.2	8.3
7				7			
6				6			
5				5			
4				4			
3				3			
2				2	x		
1	x	x	x	1		x	x

	Operations and sub-operations														
LoAmech	9.1	9.2	9.2.1	9.3	9.3.1	9.4	9.4.1	9.5	9.6	9.6.1	9.7	9.7.1	9.8	9.9	9.9.1
7															
6															
5															
4			x		x		x								x
3	x														
2															
1		x		x		x		x	x	x	x	x	x	x	

	Operations and sub-operations														
LoAinfo	9.1	9.2	9.2.1	9.3	9.3.1	9.4	9.4.1	9.5	9.6	9.6.1	9.7	9.7.1	9.8	9.9	9.9.1
7															

6															
5															
4															
3															
2															
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	Operations and sub-operations																		
LoAmech	10.1	10.2	10.2.1	10.3	10.3.1	10.4	10.4.1	10.5	10.6	10.6.1	10.7	10.7.1	10.8	10.9	10.9.1	10.10.	10.10.1	10.11	10.11.1
7																			
6																			
5																			
4			x		x		x								x		x		x
3	x																		
2																			
1		x		x		x		x	x	x	x	x	x	x		x		x	

	Operations and sub-operations																		
LoAinfo	10.1	10.2	10.2.1	10.3	10.3.1	10.4	10.4.1	10.5	10.6	10.6.1	10.7	10.7.1	10.8	10.9	10.9.1	10.10.	10.10.1	10.11	10.11.1
7																			
6																			
5																			
4																			
3																			
2																			
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	Operations			Operations	
LoAmech	11.1	11.2	**LoAinfo**	11.1	11.2
7			7		
6			6		
5			5		
4			4		
3	x		3		
2			2	x	
1		x	1		x

	Operations			Operations	
LoAmech	12.1	12.2	**LoAinfo**	12.1	12.2
7			7		
6			6		
5			5		
4			4		
3			3		
2			2		

1	x	x	1	x	x

	Operations										Operations								
LoAmech	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	**LoAinfo**	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9
7										7									
6										6									
5										5									
4		x		x			x			4									
3					x	x			x	3									
2										2							x		
1	x		x					x		1	x	x	x	x	x	x		x	x

	Operations				Operations		
LoAmech	14.1	14.2	14.3	**LoAinfo**	14.1	14.2	14.3
7				7			
6				6			
5				5			
4		x		4			
3				3			
2				2			
1	x		x	1	x	x	x

	Operations				Operations		
LoAmech	15.1	15.2	15.3	**LoAinfo**	15.1	15.2	15.3
7				7			
6				6			
5				5			
4				4			
3			x	3			
2				2	x		x
1	x	x		1		x	