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Development of an Ergonomic Screening Tool for Assembly Work

A study with the purpose to identify risks of musculoskeletal disorders

Master's thesis in Production Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Visualization showing an operator assessing a station with the ergonomic screening tool in the assembly factory.

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Abstract

Assessing ergonomics of assembly work is a complicated task that requires a high level of knowledge and a large amount of time. By using a screening tool, the stations where further ergonomic assessments are needed can be identified. This thesis includes an investigation of how the current screening tool at the assembly plant in Volvo Cars Torslanda currently performs. Following this, an improved version of the screening tool was developed with changes that reflect the found areas of improvements.

Analysis of the current state of the screening tool was divided into a quantitative and a qualitative part. The quantitative work involved extracting work injury data and comparing it to the result of the screening tool assessments. The qualitative part included interviews with the stakeholders of the screening tool with the goal to identify its improvement areas. The analysis showed that there exists a correlation between the results of the screening tool assessments and the work injuries reported. Despite this it was difficult to draw any detailed conclusions as the data set available was limited and inconsistent. The qualitative part made it clear that the tool relies on interpretations from the user and that the screening tool lacks the ability to assess multiple stations, which a workday often consists of.

Before creating the new screening tool the ergonomic standard of Volvo Cars and documents of the Swedish Work Environment Authority were thoroughly studied to ensure that all necessary areas were included and assessed. This information combined with the areas of improvement resulted in a tool that enables an objective evaluation of stations. The tool is also designed to be as user-friendly as possible with a simple design and with automatic calculations. The new screening tool also enables automatic assessment of multiple stations combined into a shift.

Keywords: risk assessment, manual handling operations, assembly work, musculoskeletal disorders, ergonomics, ergonomic screening tool, rotation screening tool.

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Lastly, we would like to thank production leaders, safety delegate members, process engineers, Health & Safety specialists, and ergonomists who participated in interviews. Also, thanks to everyone in the assembly plant who were very helpful and cooperative during our observations.

Erika Lindqvist & Rasmus Karlsson, Gothenburg, May 2019

Definitions of Terms

Term	Definition
ATACQ	Answers To All Car Questions
BAuA	German Federal Institute for Occupational Safety and Health
ErgoRAV	Ergonomic Risk Analysis Volvo Cars
EU	European Union
KIM	Key Indicator Method
KIM-MHO	Key Indicator Method - Manual Handling Operations
KIM-MHO E	Key Indicator Method - Manual Handling Operations Extended
KIM-PP	Key Indicator Method - Pushing and Pulling
KIM-LHC	Key Indicator Method - Lifting, Holding and Carrying
NIOSH	The National Institute for Occupational Safety and Health
OWAS	Ovako Working posture Assessment System
PVC	Produktionsverkstadschef (Production Workshop Manager)
RAV	Risk Analysis Volvo Cars
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
SPA	Volvo Scalable Product Architecture platform
TC	Torslanda C-shop
TIA	Teknikföretagens Informationssystem om Arbetsmiljö (Technology companies' information system on work environment)
VCC	Volvo Cars Corporation
VCT	Volvo Cars Torslanda

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1 Introduction

Chapter one presents background information, aim, and the specification of the issue under investigation.

1.1 Background

Physical ergonomics can, in short, be described as the science of how the anatomical, physiological, biomechanical, and anthropometric characteristics are related to physical activity [1]. Musculoskeletal disorders are common among assembly workers because the work often consists of repetitive work and heavy workloads. Assessing a workplace where workers are at risk for work-related musculoskeletal disorders is complex and difficult. There exist several ergonomic assessment methods that capture different areas. The main challenge is to select the appropriate method for the situation in question [2]. These ergonomic assessment methods mainly focus on individual assembly work at station level and do not pay attention to the work allocation at the whole assembly line [3].

Problems with ergonomics at the assembly plant at Volvo Cars have been, and still are, a big issue. A few years ago a new platform, the SPA (Volvo Scalable Product Architecture platform) platform, was introduced at the assembly line. The new platform resulted in a more complex ergonomic situation for the production operators in the plant than what then previously. The RAV (Risk Analysis Volvo Cars) was developed as a basic risk assessment tool in order to visualize and communicate physical risks at the stations in the plant. The RAV is today used as a screening tool globally, in all plants, and Volvo Cars rely on the tool to indicate where there are physical risks. The RAV generates two levels of results; green and red. Red means that that risks have been identified and that amendments need to be made. In some cases there is also need for an additional, more thorough, assessment, for example in the ergonomic part of the RAV, the ErgoRAV (Ergonomic Risk Analysis Volvo Cars), the additional assessment is performed by a licensed ergonomist. VCT (Volvo Cars Torslanda) desires to know more about how the ErgoRAV answers to musculoskeletal disorders in the assembly plant and if it captures the ergonomic risks. Currently, there exist conflicts between the shop floor workers at Volvo Cars Torslanda and the results which the ErgoRAV generates. The credibility of the ErgoRAV is questioned and the connection between assessments of risks and the actual outcome of health issues are disputed. The ideal case for Volvo Cars would be an ergonomic screening tool that captures the ergonomic risk areas and where the results do not raise conflicts between parties.

1.2 Aim

The purpose of the project is to present a current state analysis of how the ergonomic part of the RAV, the ErgoRAV, is currently performing. This will be made by analyzing correlations between ErgoRAV assessments and reported injuries from the operators. The project will also aim to develop a new version of the ErgoRAV that addresses the shortcomings of the previous version to increase the credibility of the results.

1.3 Project Limits & Delimitations

- The project will be performed in the assembly plant at Volvo Cars in Torslanda, Gothenburg. This means that the developed tool will be adapted to work in the assembly plant.
- The project will be delimited to only include the ergonomic part of the RAV screening tool, called the ErgoRAV.

1.4 Specification of Issue Under Investigation

Following questions are aimed to be answered when presenting a current state analysis of how the ErgoRAV performs:

- What effects does the current version of the ErgoRAV have?
- How trustworthy is the ErgoRAV today?
- What does a station that has been evaluated as red in the ErgoRAV actually mean for the operators in terms of working conditions?

Following questions are aimed to be answered when developing a new version of the ErgoRAV that addresses the shortcomings of the previous version:

- How can the ErgoRAV be changed to increase the accuracy of the screening?
- How can the new ErgoRAV be used to analyze several stations (a rotation)?

2

Theory

This chapter aims to present the necessary theories on musculoskeletal disorders and ergonomics evaluation methods, which guide the work and support the results.

2.1 Musculoskeletal Disorders

Musculoskeletal disorders are a very common health problem. They constitute one of the health problems with the highest impact on sickness absenteeism in Europe, standing for half of all absences from work according to the European Agency for Safety and Health at Work, [4]. This also means that it is very costly for the countries and companies affected, not to mention losses regarding productivity. The automotive manufacturing industry is known to have a high frequency of musculoskeletal disorders. This is mostly within the risk factor concerning the force level or the load on the joint [5]. This is due to the repetitive motions and/or heavy workloads that assembly work in the automotive manufacturing industry often requires. But what are musculoskeletal disorders? In short, they are injuries and pain which affect the human musculoskeletal system, the structure that support limbs, neck and back. The musculoskeletal system also includes joints, ligaments, muscles, nerves and tendons. Work-related musculoskeletal disorders are said to affect the physical ability to move and handle loading [6] and are often associated with:

- Repetitive work
- Forced working postures
- Static work
- Continuous loading
- Stress/time pressure
- Bad working techniques

Musculoskeletal disorders can be avoided through engineering and good knowledge of ergonomics in the form of well-designed workplaces and appropriate work methods that match the physical ability of the worker. It is therefore important to identify the risks which can lead to musculoskeletal disorders early on in the process. Musculoskeletal disorders can also be prevented by introducing variation of work tasks to prevent the assembler from loading the same parts of the body monotonously and repetitively. According to Oakman et al., (2018) [7] actions performed to remove risks for musculoskeletal disorders can also be made through changing workers' behaviours through training programs, which is preferably better than addressing risk from work-related hazards at their source.

2.2 Ergonomics Assessment Methods

There exist several ergonomic methods, all with the main purpose to optimize human well-being. The methods often focus on a specific type of task or body section. Some address a combination of several areas:

- Posture analysis methods
  - REBA (Rapid Entire Body Assessment) [8]
  - RULA (Rapid Upper Limb Assessment) [9]
  - OWAS (Ovako Working posture Assessment System) [10]
- Biomechanical assessment methods
  - NIOSH (The National Institute for Occupational Safety and Health) [11]
  - Liberty Mutual materials handling tables [12]
- Combined methods
  - KIM (Key Indicator Method) [13] [14] [15]

Mostly methods have the purpose to quickly screen and identify harmful postures. The following sections will contain information on the different methods.

2.2.1 Rapid Entire Body Assessment

REBA [8] focuses on when work is being performed by the entire body. The assessment focuses on one posture at the time. Focus areas which are analyzed are:

- Neck position
- Trunk position
- Leg position
- Arm position
- Wrist position
- Lower arm position
- Gripping
- Force/load

A score is being calculated from the answers on these areas the result says what the risk of that position is, from negligible risk to a very high risk.

2.2.2 Rapid Upper Limb Assessment

RULA [9] only focuses on the upper limbs, meaning hand- and arm intensive work. This method is mainly useful when the work is being performed sitting. REBA and RULA have similar layouts, they both assess only one posture and the score from the different focus areas are used in a calculation which says what risk there is. The focus areas for RULA are:

- Upper arm position

- Lower arm position
- Wrist position
- Neck position
- Trunk position
- Statistic or repeated work
- Force/load

2.2.3 Ovako Working posture Assessment System

OWAS [10] also assess a specific posture and the risk of working in this posture. It also focuses on the load handled when working in this posture. In the assessment one can choose from different postures within the following focus areas:

- Back position
- Arms position
- Legs position

In the focus area concerning the position of the back one can choose from 4 different postures. From the arm focus area there are 3 different postures to choose from and from the leg focus area there are 7 postures. When picking the suitable postures for the different areas and the load used a score can be read from a matrix which tells what the areas with the highest risks are.

2.2.4 The National Institute for Occupational Safety and Health

NIOSH is the American equivalent to the Swedish Work Environment Authority. They developed a lifting equation method which they use to tell if lifting a certain load is acceptable or not. The NIOSH lifting equation method [11] is one of the biomechanics-based analyzes. The method answers to if the weight is too heavy for the task, referred to as the recommended weight limit, and how significant the risk is, referred to as the lifting index.

2.2.5 Liberty Mutual materials handling tables

Liberty Mutual is an American insurance company who created tables as an ergonomic analysis tool. The goal with the Liberty Mutual materials handling tables [12] is to support ergonomic design interventions by assessing the areas:

- Lifting
- Lowering
- Pushing
- Pulling
- Carrying tasks

Taken into consideration is the height of what is to be lifted, the weight of it, the hand distance and height before and after the object has been lifted, and how often the task is being performed. It also consider the distance which the object is being pushed or pulled.

There are several different tables, for both males and females, which concludes information on the capabilities for the above mentioned areas. The tables has the purpose to tell who should be able to perform the tasks.

2.2.6 Key Indicator Method

The German Federal Institute for Occupational Safety and Health (BAuA) are responsible for the development of KIM screening methods. There currently exists three variants of KIM. The screening methods that are used for operations regarding manual handling of loads are:

- **KIM-LHC (Key Indicator Method - Lifting, Holding, and Carrying)**
  Concerns lifting, holding, and carrying [13]
- **KIM-PP (Key Indicator Method - Pushing and Pulling)**
  Concerns pushing and pulling [14]
- **KIM-MHO (Key Indicator Method - Manual Handling Operations)**
  Concerns manual handling operations [15]

The KIMs are recommended by the Swedish Work Environment Authority and they refer to the methods differently than BAuA, see Table 2.1.

Table 2.1: The KIMs expressed from BAuA compared to the Swedish Work Environment Authority.

BAuA	Swedish Work Environment Authority
KIM-LHC	KIM 1 [16]
KIM-PP	KIM 2 [17]
KIM-MHO	KIM 3 [18]

The two methods KIM-PP or KIM-LHC, are meant for activities which involve manual handling of loads where the weights excess 5 kgs [19]. KIM-MHO assesses work activities predominantly involving exposure to the finger-hand-arm area when working on physical objects (manual tasks).

KIM-MHO, which is applicable for repetitive tasks where the weight does not exceed 5 kgs, takes similar areas as KIM-LHC into account. These areas are:

- The duration of the manual handling operation
- Type of force exertions and how long/how often it is performed
- Conditions regarding applied force transfer and grip
- Hand/arm position and movement

- Work organization
- Work conditions
- Body posture

All areas have rated points which are used to generate a result establishing the risk level for the operator. KIM-MHO is performed in similar steps as for KIM-LHC but the content within the steps differ slightly between the two which can be seen in section below.

There are four different risk levels applicable for all three KIM-methods. The first is classed as "green" and indicates a low exposure situation. The second is classed as "greenish yellow" and indicates that there is an increased exposure situation. The third, "yellow", signals a highly increased exposure situation where a redesign of the workplace is recommended, and the last category is "red" which indicates a high exposure situation and a redesign of the workplace is necessary [19].

Currently, the KIMs published on the BAuA webpage are only applicable for assessing one work task at a time. It is therefore not possible to use any of them to assess a number of tasks or a whole work day. For this purpose, BAuA is currently developing a new tool, KIM-MHO E (Key Indicator Method - Manual Handling Operations Extended) that creates the possibility to assess multiple tasks and get a combined result from the tasks. Through personal communication BAuA was kind to share this tool. How this is calculated is presented in section 5.3.3.

Key Indicator Method - Manual Handling Operations
KIM-MHO can be described with the following steps [15] [20]:

1. The time score is decided where the user needs to know the total duration per shift of the activity which is being assessed.
2. The rating points is determined for the type of force exertion, gripping conditions, work organization, working conditions, posture and hand/arm position, and movement.
3. The evaluation of the risk score is performed which is the sum of the type of force exertion(s) in the finger-hand range, the force transfer/gripping conditions, the hand/arm position and movement, the work organization, the working conditions, and the posture.
4. All points are multiplied from step two and three with the time rating points from step one.

These steps of KIM-MHO can also be expressed with the following equation:

$$Risk\ score_{KIM-MHO} = Time\ points * (P_{Force\ exertion} + P_{Gripping\ conditions}$$
$$+P_{Work\ organization} + P_{Working\ conditions} + P_{Posture} + P_{Hand/arm\ position\ and\ movement})$$

where:

$P_{Force\ exertion}$	:	Rated points for the force exertions
$P_{Gripping/:conditions}$	:	Rated points for the gripping conditions
$P_{Work/:organization}$	:	Rated points for the work organization
$P_{Working\ conditions}$	:	Rated points for the working conditions
$P_{Posture}$	:	Rated points for the posture
$P_{Hand/arm\ position\ and\ movement}$	:	Rated points for the hand/arm position and movement

Key Indicator Method - Lift, Hold, and Carry
KIM-LHC can be described with the following steps [13]:

- The first step of KIM-LHC is to determine the time rating points, how long the worker is lifting, holding or carrying.
- The second step is to determine rating points for load, posture and working conditions.
- The third step is to calculate the risk score.

KIM-LHC can be further explained with the following formula:

$$Risk\ score_{KIM-LHC} = Time\ points * (P_{Load} + P_{Posture} + P_{Working\ conditions})$$

where:

P_{Load}	:	Rated points for load
$P_{Posture}$	:	Rated points for the posture
$P_{Working\ conditions}$	:	Rated points for the working conditions

3
Methods

This chapter aims to describe how the work was performed and what type of results that are expected from the used methods. The method in which the work will be based on can be described as the empirical cycle [21], see Figure 3.1.

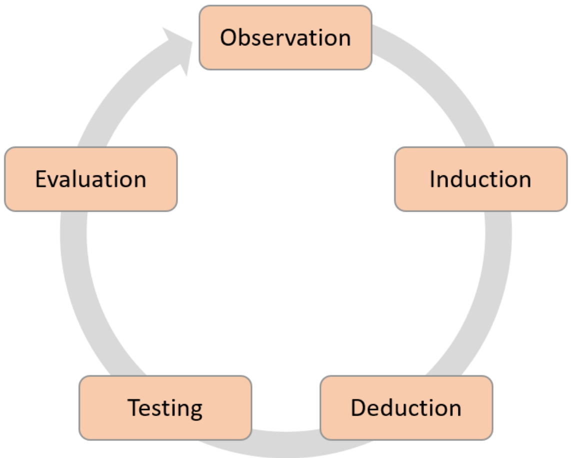


Figure 3.1: A.D. de Groot's empirical cycle [21]

The stages in the empirical cycle connected to this project:

- **Observation**
  Observations are made in order to describe the problem. The observations was mainly about getting familiar with the problem. This included observations in the assembly plant and meetings with stakeholders. A current state analysis is performed based on quantitative and qualitative data collection did describe what the problem actually is.
- **Induction**
  The quantitative data will be combined with the data from the interviews and conclusions will be drawn regarding the reasons for the problem.
- **Deduction**
  A new, improved screening tool will be developed to address the shortcomings found in the induction step.
- **Testing**
  Tests of the new screening tool will be performed in the assembly plant and data from these are collected. This will result in data on how the tool performs.

- **Evaluation**
  The tests are evaluated and verified through meetings and comparison to present results.

A flowchart of the methodology of this project can be seen in Figure 3.2.

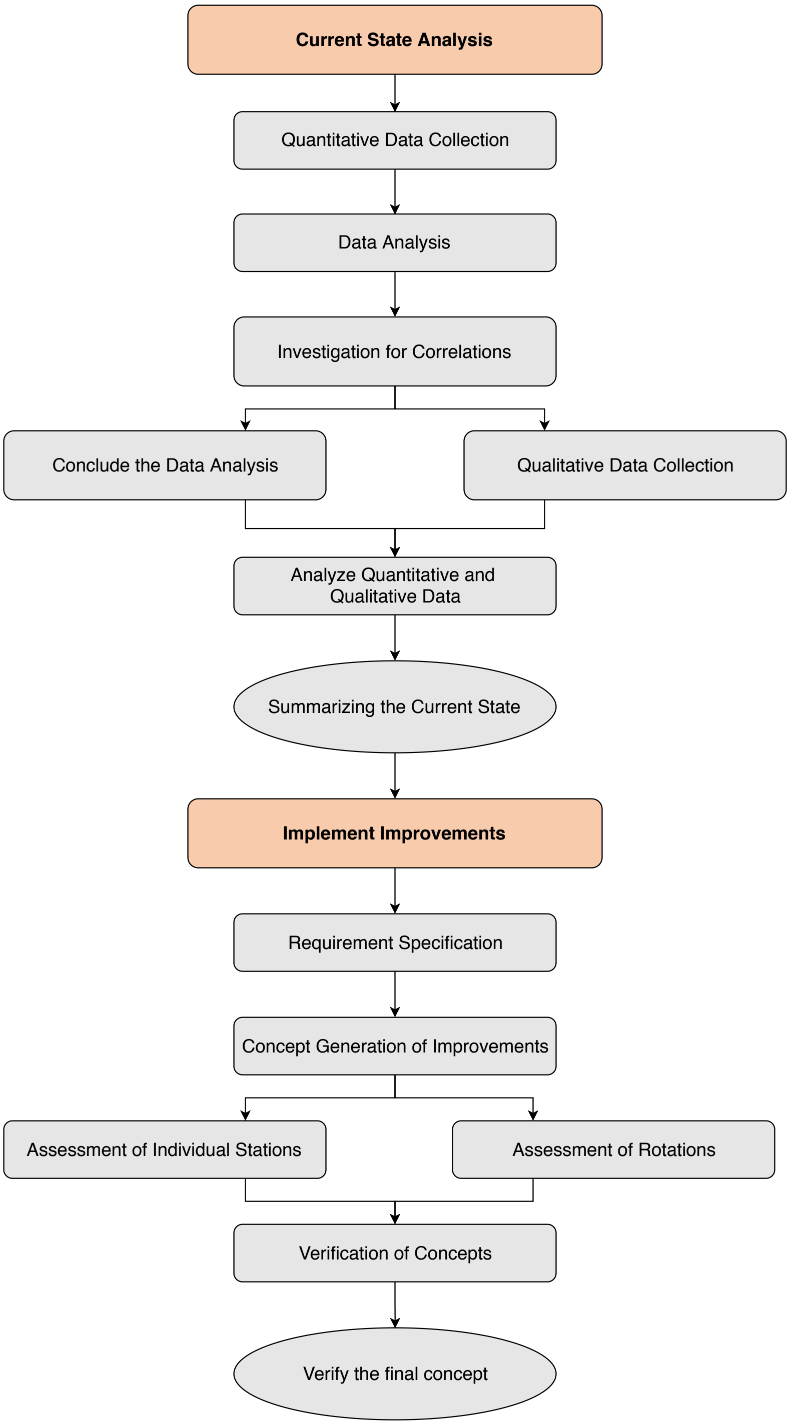


Figure 3.2: Flowchart for the project

3.1 Current State Analysis

Quantitative and qualitative data are often used in combination to compensate for the weaknesses of each method. While quantitative methods generate objective information where the evaluator has little effect on the result, qualitative data can generate contextual understanding to the problem [22].

The goal with the current state analysis was to produce credible information that describes how the ErgoRAV currently performs. In this project, both quantitative data from databases, and qualitative data in forms of interviews with the different stakeholders of the ErgoRAV, was collected. The stakeholders in this project are defined as everybody that is affected by the ErgoRAV, e.g. operators, production leaders, safety representatives, VCT management, etc.

3.1.1 Quantitative Data Collection

The quantitative data was extracted from a number of different databases within the infrastructure of VCC (Volvo Car Corporation). Since the assembly plant is constantly changing, all data that was collected was created in the year of 2018. This is to get results that reflect the present as closely as possible. The data covered all the PVC-areas (Production Workshop Manager) in the assembly plant, and the detail level was at department level. The reason for this is that the report for work injuries includes neither station or team. Below, all types of data which will be collected and the corresponding database will be described.

3.1.1.1 Data of ErgoRAV Assessments

The data for the ErgoRAV assessments are stored on an online Microsoft SharePoint page on the VCT intranet. This data includes the result of ErgoRAV assessments on all stations with the date of the assessment and historical data on assessments for the latter half of the year 2018. The online SharePoint was created during 2018, therefore the history of the digital data has only been updated since then. This database also presents data on ergonomic evaluations performed by ergonomists, if they have been performed on the station. The collected data will be extracted to Microsoft Excel and categorized according to department.

3.1.1.2 Data of Work Injuries

Work injury data exists in a system called TIA (Technology companies' Information system on work environment). In the TIA system, all work-related health issues are reported by the production leaders. The database is managed by Health & Safety that investigate all the reported events and makes decisions if further actions need to be taken. The data interesting for this project are health issues related to musculoskeletal disorders, information regarding the time of injury occurrence, department of the injured, a description of the injury, and the cause of the injury. The data will be imported into Microsoft Excel and the events that could be related to the ergonomic situation will be extracted. Health & Safety provides the data and can hide all personal information related to the injuries, such as names and personal identification number, before it is processed.

3.1.1.3 Data of Assembly Errors

To be able to find possible correlations between ergonomics and assembly errors, quality data will be collected. This data is generated automatically by automatic tools and is handled by a system called ATACQ (Answers To All Car Questions). The ATACQ system receives data from tools and flags when deviations occur. It is also possible for authorized personnel to manually enter production deviations into the system, deviations such as lacquer damages. The parameters interesting for this project are the number of assembly errors of a specific department.

3.1.2 Data Analysis

Describing the relationship between the data sets was the main goal with the data analysis. By calculating the Pearson product-moment correlation the relationship was quantified with a number between -1 and 1. A correlation between -1 and 0 implies a negative correlation meaning if variable A increases, the value of variable B decreases. If the correlation is between 0 and 1, there exists a positive correlation meaning that one variable increases with the other. A correlation value close to 1, implies that both variables change at the same rate [23].

The data will be visualized and analyzed with the software JMP. JMP is a software for statistical analysis that simplifies the process of finding a correlation between different data sets. It is especially useful for discovering a correlation between data sets where correlation is not anticipated. In this project this will be useful as other, still unknown factors, might affect the result of the ErgoRAV assessments or the reported work injuries in the TIA database. By using the software pitfalls such as biased samples, over-generalization and incorrect analysis are avoided.
Mainly, the correlation between work injuries and red ErgoRAVs will be analyzed using the Pearson product-moment correlation. Seeing how work injuries affect the quality of the assembly work is important to even further strengthen the importance of good ergonomic conditions.

3.1.3 Conclusion of Data Analysis

When correlations and missing correlations have been found on a plant level, the investigation was continued to look into where correlations between ErgoRAV assessment and work injuries exist. At which departments did it seem to correlate and at which departments did it not? Did the departments where correlations exist have something in common? By answering those questions, some of the strengths and weaknesses of the ErgoRAV was aimed to be found. The data available is not more detailed than department level so to find specific areas where the ErgoRAV fails to deliver accurate results, investigations on the shop floor was performed. The methodology for this investigation depended on what needed to be investigated.

From the extracted information from the data analysis and correlation investigation, conclusions will be drawn to how the ErgoRAV actually performs. The aim is for these conclusions to be fully objective and only rely on data and facts from the shop floor.

3.1.4 Qualitative Data Collection

The qualitative data was collected through interviews with employees who work with or is affected in their work by the ErgoRAV.

Choosing the correct type of interview structure was important to gain the right type of knowledge. Structured interviews, where all questions are exactly the same for each interview, are appropriate when there is a need to answer questions where the quantitative data is of interest. If there needs to be an understanding of the reasoning behind the questions, semi-structured interviews gives this opportunity [24]. Semi-structured are appropriate to use when the subject of the wanted knowledge is known, but space for more open discussions is beneficial.

In this project, there was a need to find out the reasoning behind the answers at the interviews since this will be the foundation for the development of the new ErgoRAV. A structured interview might answer questions that deliver information on the level of satisfaction of the current ErgoRAV. Though, it will not generate any information on why they are satisfied or unsatisfied or where there is room for improvement. In this project, semi-structured interviews will be the chosen methodology for qualitative data collection.

Interviews was held with the stakeholders that are affected by the ErgoRAV in their work. The questions asked in these interviews differed depending on the interviewee's role. The aim was to have semi-structured interviews that investigate the current state of the ErgoRAV and also provided data on what is expected from the ErgoRAV. All interviews will be held anonymously throughout the project. The questions that were asked at all interviews regarding the ErgoRAV was:

- How does the ErgoRAV affect your daily work?
- How do you experience working with the ErgoRAV?
- Do you trust the results that the ErgoRAV provide?
- Do you have any expectations on the result that the ErgoRAV provides?
- What do you expect from the interplay between ErgoRAV and ergonomist?
- Do you always trust the evaluation from the ergonomist?
- What do the ErgoRAV results mean for the operators?
- What role should the ErgoRAV have?
- In your opinion, what is the general perception of the ErgoRAV?
- Do you think that the ErgoRAV has had any shortcomings?
- What do you think of the parts that are currently in the ErgoRAV?
- Do you think additional sections should be added to the ErgoRAV?

- How well do you think the interplay between ergonomist and the ErgoRAV works today?

The first step is to interview production leaders to compare if the process of reporting work injuries in the TIA system differs from department to department. The questions that will be asked specifically to production leaders are:

- What does the process look like, from when someone is feeling unwell, to when it is reported into the TIA database?
- Is everything reported into the TIA database or how do you choose what is reported?
- What is the rate of operator turnover like at your the department?
- Do you perceive that there occur many work injuries at your department?

3.1.5 Summarizing the Current State

The data from the interviews was compared to the conclusions from the data analysis. This resulted in deeper knowledge surrounding the issues and provided a foundation for a specification of an improved ErgoRAV tool. The last step of the current state analysis was to summarize the conclusions in a way that was easy to comprehend for all the stakeholders of the ErgoRAV. The results was delivered in the form of tables, diagrams, and bullet lists, and will be a stable and reliable base for continuing with the improvement process of the ErgoRAV.

3.2 Improvements to the ErgoRAV

In this section, the procedure of developing improvements to the RAV, including the ErgoRAV tool will be described. The questions that will be generated for the ErgoRAV was considered for what is currently defined as the RAV team in section 4.1.4. If the RAV team is not complete then all questions cannot be fairly answered. A detailed instruction will be created that stipulates the requirements for assessing the ErgoRAV and describes the questions step by step.

What should be included in the ErgoRAV is decided by regulations, current standards, and the stakeholders' opinions. In this section, the methodology of extracting the requirements will be presented and explained in detail.

3.2.1 Requirements from Regulations and Standards

The purpose of the ErgoRAV is to enable the possibilities to rapidly check the state of the working conditions. The goal with this is to generate good enough working conditions in order to avoid operators being affected by musculoskeletal disorders. In the means of this project, this equals to working conditions that follow the demands set by both the Swedish Work Environment Authority and the VCC ergonomic standard. The ErgoRAV, therefore, needs to include all the areas treated by the AFS 2012:2 and the VCC ergonomic standard. To identify these areas, all demands from the VCC ergonomic standard will be extracted into a list that will be compared to a checklist based on AFS 2012:2. The result will be a list of demand areas that need to be included in the ErgoRAV. Some of the demands from the AFS 2012:2 are more detailed in the VCC ergonomic standard and vice versa.

3.2.2 Requirements from Stakeholders

In addition to the demands from the Swedish Work Environment Authority and the VCC ergonomic standard, requirements from the stakeholders will be taken into account. The requirements will be extracted from the interviews with the stakeholders of the ErgoRAV, where questions about expectations are asked. These expectations will be opinions from the people that are in some way affected by the ErgoRAV. This can be from both users of the tool and people whose work is affected by the results of the ErgoRAV which means that these requirements will include both usability aspects and result aspects.

3.3 Concept Generation of the Improvements

The concept generation will be divided into two stages. The first stage will have the purpose to design the ErgoRAV for assessment of individual stations. The second stage will have the purpose to implement a method to enable assessment of a rotation. The concepts will be created in Microsoft Excel. Based on the ergonomic evaluation methods in section 2.2 the method most suitable will be used when generating the concept.

3.3.1 Assessment of Individual Stations

The concept of the new ErgoRAV will be developed from the requirements mentioned in section 4.2. The requirements will be categorized and grouped into suitable categories. Questions for the ErgoRAV will be phrased to include everything in those categories.

3.3.2 Assessment of Rotations

The assessment of rotations is important at VCT since job rotation is an approach currently used to avoid musculoskeletal disorders in the plants. The assessment should enable the possibility to analyze how, and if, the job rotation can be used to relieve the operator from fatiguing tasks. The assessment of a rotation should give information on how rotating between the stations affect the risk of contracting musculoskeletal disorders originating from a bad ergonomic situation.

3.4 Verification of Concepts

The concepts will be discussed with the stakeholders and tested in the assembly plant. Properties such as usability and accuracy of the result will be analyzed.

3.4.1 Testing the Concepts in the Assembly Plant

Before involving the stakeholders in testing, the concepts will first be evaluated by the project team. The testing procedures will follow the PDSA cycle; Plan, Do, Study, Act. This methodology provides a defined structure for improvement work and will provide a basis for the tests of the ErgoRAV[25]:

- Plan - Planning the tests and studying the stations where the concepts will be tested.
- Do - Performing the evaluations.
- Study - Comparing the test results and identifying possible improvements.
- Act - Implementing the improvements and testing again.

The planning phase includes deciding what teams to evaluate, how much time that will be spent at each station, and other details surrounding the procedure. To avoid the test being biased towards a good or bad result, the results of the current ErgoRAV evaluations will not be studied before the assessment. Stations and teams with different characteristics will be selected for evaluation to gain information on as many variables as possible. When the stations have been selected, the stations will be studied for a predetermined amount of time. This is to make sure that the information needed for the assessments will not be too time-consuming to collect. The evaluations will be performed individually in the plan stage to identify areas of the new ErgoRAV that allows interpretation and gives a subjective result. The results of the tests will be compared and categories, where the results differ, will be analyzed and possibly improved.

When the tests have generated a satisfying concept, meetings will be held with some of the stakeholders. In these meetings, the new concept will be presented and explained and the stakeholders' opinions will be taken into account. Areas such as usability and the results from the initial tests will be discussed.

4
Case Context

The following chapter contains information on how Volvo Cars works with ergonomics, what the RAV tool is and what it contains. It also summarizes the Volvo Cars internal ergonomic requirements. All descriptions are based on preliminary data collection from employees at VCT and internal documentation which can be found on the VCC intranet.

4.1 How Volvo Cars Works with Ergonomics

The Manufacturing Engineering department at Volvo Cars works with proactive ergonomics in early phases, development, and verification of the products. The aim of proactive ergonomics is to secure that the design of the product and process solutions consider ergonomic demands. The Industrial Engineering department works with ergonomics and technical solutions in the assembly plant. This department is responsible for ensuring the compliance of the ergonomic demands during station planning and station setup.

The ergonomic demands which apply for Volvo Cars are the VCC ergonomic standard and also standards and regulations for the country in question. The reason for VCC to work with ergonomics in early phases is to create a good work environment to prevent work-related musculoskeletal disorders and injuries for their workers.

The workflow related to ergonomics at Volvo Cars can be described as follows:

- **Annual stage**
  Communication of critical areas in the plant to the Manufacturing Engineering department. Leads to selecting critical areas where improvement is needed.
- **Concept stage**
  Develops product and process solutions that fulfill ergonomic demands.
- **Virtual verification**
  Rough balancing through software programs to fulfill ergonomic demands. Postures and work tasks are also verified in a modeling software.
- **Physical verification**
  Verifying and assessing the proposed assembly method to fulfill the ergonomic demands. Final balancing of the stations is performed.

The main purpose is to highlight the ergonomic issues at all stages in order to allocate resources to the areas that are in need of changes/improvements.

4.1.1 The Assembly Plant

The assembly plant at VCT, which can also be referred to as TC (Torslanda C-shop), is the focus area in this project. TC contains six PVC areas. For reasons of confidentiality, the PVC areas are pseudonymized and which in this project will be called:

- Area A
- Area B
- Area C
- Area D
- Area E
- Area F

Each PVC area includes several departments and one department is comparable to a line in assembly. In the assembly plant at VCT there exist 24 departments. A department is often a closed area including several teams who are assigned to perform work at several stations. At each department, there is one production leader that is responsible for areas such as personnel, work environment, safety, quality, continuous improvement and to generate action plans. For each team, there is a team leader who works at the assembly line and has the main purpose to support and help the operators. Team leaders report work injuries, accidents, and incidents in the TIA system together with the safety delegate members and the injured person in question. The team leader files a report including information about the injured in TIA which needs to be approved by the production leader. The production leader communicates with the involved parties and fills in complementary details if needed in the report before approving. When the report is approved different actions are communicated to the injured. Depending on what the report concerns the recommendations differ. The production leader is also responsible for reporting to the insurance company when injuries occur. There is an acting safety delegate member in every department. Figure 4.1 presents a hierarchical map of a department.

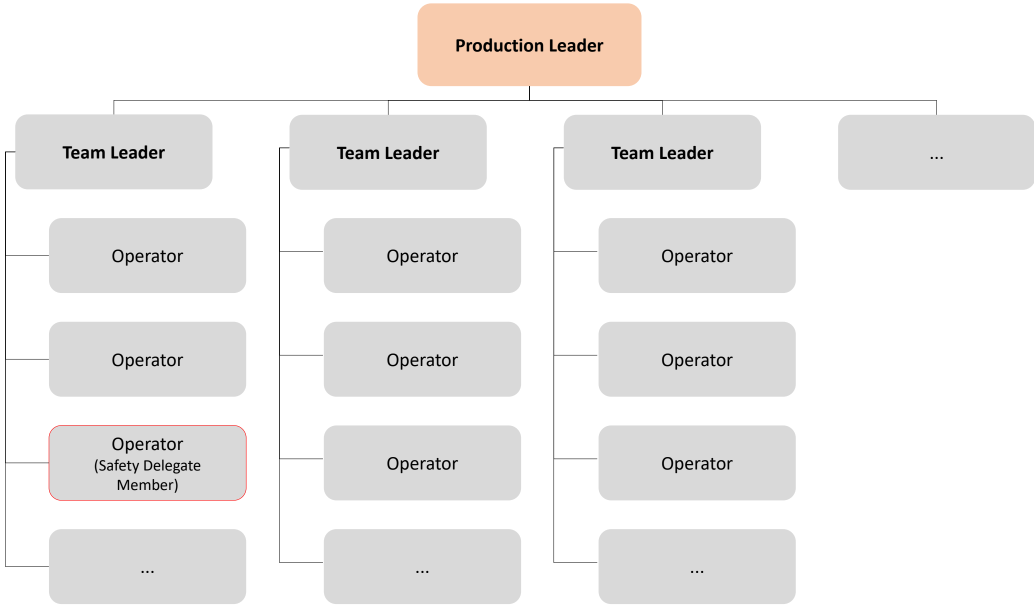


Figure 4.1: Production hierarchy of the assembly plant.

One basic routine that Volvo Cars use to improve the working conditions is to have the operators rotate between different stations to introduce some work variation. There have also been many investments in different aids, mainly lifting aids, in order to improve the ergonomic situation.

4.1.2 Health & Safety

Health & Safety is an organization within Volvo Cars that provides the RAV, that are responsible for improving the RAV and generating education material. They also have responsibility for a system called TIA which is an incident reporting system. Health & Safety also reports issues to the Swedish Work Environment Authority if there is a need for that.

Today there is one person at Health & Safety responsible for the ergonomic part of the RAV, called the ErgoRAV, which this project will focus on. Improvements with the ErgoRAV is something Health & Safety wants to work more with, but they feel like they do not have the time.

4.1.3 Ergonomic Assessments by Ergonomists

Ergonomists at Volvo Cars are provided by an outside organization called Feelgood which is a corporate health care organization. The ergonomists help with performing ergonomic evaluations of requested stations and perform ergonomic evaluations on rotations. They help with providing some of the education material for the ErgoRAV. They are also the ones who provide the ErgoRAV related educations for the employees at VCT. All of this is performed on behalf of Health & Safety.

Station evaluations from the ergonomist are divided into red, yellow and green results. Following the result, improvements and changes for the station in question are suggested by the ergonomists.

4.1.4 Screening with the RAV tool

The current RAV contains eight different work environment risk categories:

- Noise
- Lighting
- Accident risk
- Machine safety
- Chemical usage
- Ergonomics
- Electrical safety Hybrid car
- Industrial vehicles

The RAV has the purpose to identify physical risks within these eight areas. It is currently designed in a Microsoft Excel file, where the cover sheet shows the result of the RAV with additional comments. The workflow for the RAV can be described as follows:

1. The user works in the checklist where different yes/no questions concerning risks within the eight different categories are asked.
2. If the answer of any of the questions is yes, then the user continues to the sheet related to that specific area for further assessment. Within the sheets, for each area, there are more questions which are issued to highlight problem areas.
3. The question in the checklist for ergonomics is "Is there a risk of physical loads which are dangerous to health?".
4. The user answers the questions and can suggest improvements in the field for comments.

This project will focus on the ergonomic risk area, which is referred to as the Ergo-RAV.

The RAV is performed by a RAV team which usually contains a minimum of two members but preferably up to 3 to 4 members. The members are the production leader, a safety delegate member, an industrial engineer, and an operator. Requirements for the team are that they have good knowledge of the station that is being assessed and that all members must have attended a 3,5 hour education on how to use the tool. The RAV tool can be used with limited training and education and is therefore used to get quick estimations of the ergonomic situation.

When the ErgoRAV is assessed as green, there is no need for an assessment from an ergonomist. If the station gets a red result from the ErgoRAV, measures will be taken in order to see if there is a solution available so that the ErgoRAV can become green. First, the RAV team oversees if there are any changes/improvements that can be made for the result to turn green. If simple solutions are not enough an ergonomist is called to assess the station. A station with a green ErgoRAV can also sometimes need an assessment from an ergonomist but that has to be requested since the red ErgoRAV results are prioritized.

If any area in the RAV is assessed as red, then the RAV result is red, indicating that changes/improvements to that station have to be made. If all areas are green then the RAV result is green, no need for changes. This means that if the ergonomic part of the RAV is assessed as red, the end result of the ErgoRAV is red. Today the ErgoRAV contains the following seven yes/no questions where yes equals red and no equals green:

1. Absence of training/instruction in working technique? Applies also to hired staff. [Yes/No]
2. Does work with hands above shoulder height occur? [Yes/No]
3. Does work with the neck or the trunk of the body bent or twisted occur? [Yes/No]
4. Does work with hand/wrist bent or twisted occur? [Yes/No]
5. Occurs squatting, kneeling or crouching positions? [Yes/No]
6. Is work/manual handling, that requires high effort, with a work object, work equipment, controls or material, perceived as unnecessarily fatiguing? [Yes/No]
7. Are there any lifting perceived as heavy? [Yes/No]

Question 2-5 receives a red result (if answered "Yes") if the total time in the work posture exceeds 20% of the working time on the station being evaluated, or if it is frequently repeated i.e repeated more than 1 time per minute.

Regarding question 7, if the answer is yes the user is referred to an external document. The external document is the ergonomic assessment method, KIM-LHC (Key Indicator Method - Lifting, Holding and Carrying). KIM-LHC contains questions regarding the assessment of manual handling and will be further presented in section 2.2.6. The points generated from the KIM-LHC assessment decides the answer (red or green) for question 7. If any of the questions receives a red result, the final result of the ErgoRAV on that station is red.

It is stated in the education material that the RAV assessment should be updated at least once a year, when changes to the station are made, when there are comments from the safety rounds, or when an accident or incident occurs. It is also stated the RAV assessment must be visually available at each station.

4.2 Standards and Requirements

There are several standards, regulations, and directives concerning ergonomics which affect the design of a workplace. Volvo Cars have their own standard and each country has different regulations and directives which need to be taken into consideration. This section aims to present the VCC ergonomic standard provided by Volvo Cars.

4.2.1 Ergonomic Requirements at Volvo Cars

Volvo Cars have their own standard related to ergonomics which conforms to Council Directive 90/269/EEC issued by the Council of the European Communities [26]. The requirements in the standards need to be followed in all Volvo Cars' production facilities in Sweden and are applied together with Swedish work environment legislation: AFS 2012:2 Ergonomics for the prevention of musculoskeletal disorders [27]. In countries other than Sweden the requirements in the standard are applied together with the work environment legislation in the country of concern. Legislations in each country are the minimum requirements, but if the standard has higher demands, the standard applies. Lastly, the standard refers to European requirements, EN 1005 parts 1-4 regarding Safety of machinery - Human physical performance, and to EN 614-1 regarding Safety of machinery - Ergonomic design principles.

According to the standard, a good ergonomic workplace places demands on the product, process, operator, as well as the organization. Work tasks and workplaces need to be designed in a matter which provides variation and job rotation or change of tasks for the operator. It is also important to highlight that people are different, meaning they have different capacities which must be taken into consideration when meeting the range of requirements such as age, sex, and physical capacity.

It is stated in the standard that during at least 80% of the work time throughout the day, the operator should be able to work in a comfortable and ergonomically correct work posture. This means that the body is postured in neutral positions and that there are various working movements for the operator. Working incorrect could mean uncomfortable postures and working movements. This can lead to static muscular work, highly repetitive work, having arms lifted, shoulders raised, back bent forwards, all in which increases the risk for injuries.

The standard also covers the area of material handling. It mentions how work heights are affected by large and heavy parts, how it should not be necessary to lift the part over clamps or lugs, packages should be easy to handle, conditions for visual inspection should be adaptable, and how lifting aids need to be investigated on stations which require lifting.

There are several notes regarding pressure forces in the standard where it is mentioned how large the pressure area should be and how it should be formed. It is also stated what pressing direction should be used, how fasteners and clips need to snap/give an indication to the operator when correctly mounted, and what pressure forces that are allowed for different parts.

Vibration levels on hand-held machines and tools need to be as low as possible. Tools should also be as light and well balanced as possible and grips/handles needs to be long enough to hold the entire width of the hand. Variation of tasks, job rotations, are of high importance. The standards also address material-handling vehicles which include how the truck should be designed with respect to the truck operator.

4.2.2 Swedish Regulations

All Swedish companies are affected by the Work Environment Act or other legislation provided by The Swedish Work Environment Authority. There is one regulation called AFS 2012:2, which cover ergonomics for the prevention of musculoskeletal disorders from The Swedish Work Environment Authority's Statute Book with the purpose to design workplaces and tasks, to prevent risks of health-endangering or unnecessarily fatiguing loads [27].

The regulation states that it is the employer who has the responsibility to investigate if the operators perform work which requires bad work postures and working movements, health-endangering or unnecessary fatigue when performing repetitive work and manual handling. All in which to avoid musculoskeletal disorders, meaning that all forms of ill-health in the musculoskeletal system connected with the working conditions.

4.2.3 EU Directives

There are several directives from the EU (European Union) concerning questions regarding ergonomics which all countries in the EU must follow. Two directives are about the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents concerning vibrations [28] and noise [29]. Both directives present limit values and exposure action values. Another directive has the purpose to introduce measures to encourage improvements in the safety and health of workers at work [30]. Lastly, one important directive concerning manual handling of loads which lays down the minimum health and safety requirements [31].

5
Results

The following chapter will present the findings and what the results of these were. This will be sectioned into two main parts:

- Current state analysis
- Improvement of the ErgoRAV

5.1 Current State Analysis

A quantitative and qualitative data collection has been conducted in order to describe the current performance of the RAV. In this section, the analyzed data and the conducted results will be presented.

5.1.1 Quantitative Data Collection

Mainly there have been three categories where the quantitative data has been collected. These are the ErgoRAV assessments, work injuries, and assembly errors. The following sections will describe the results from these categories in more detail.

5.1.1.1 Data of ErgoRAV Assessments

The SharePoint includes the following information from the ErgoRAV assessments:

- The result of the ErgoRAV assessment
- Name of the station
- Team number
- Department
- PVC area
- Date of the last assessment
- An attachment of the RAV document
- Version history

The latest ErgoRAV assessment should also be visualized at each affected station on the shop floor, but it came to the realization that this was not always the case. The production leader together with the team leader is responsible for updating the visualized material at the stations, but it seems like it is often forgotten to update the old assessments when new ones are made. On several assessments, dates were missing and the field where the user should fill in the date said to see the back of the paper which is not visible in the digital version. Investigations on the shop floor were made, and it resulted in finding a backside on the RAV cover sheet which contained information regarding updates. Here the user fills in information such as department number, name, RAV team members, and the station being assessed. In most cases, it seemed like the team filled this sheet manually which made it impossible to digitally trace when the RAV was being performed. This information was important since the RAV was later to be connected to the reported injuries on the assessed station.

5.1.1.2 Data of Work Injuries

The TIA system gave the possibility to generate all data related to health issues related to musculoskeletal disorders during 2018 connected to when the injury occurred. The TIA system contains data such as:

- The department where the injury occurred
- Type of injury
- Cause of the injury
- Date of the injury

In order to get as accurate a result as possible, each injury needed to be paired with the ErgoRAV assessment which was valid at the time of the injury. Some assumptions were made when calculating how the assessments looked at the time of the incident since some assessments were lacking specific dates. The SharePoint generates user history made throughout 2018 which made it possible to connect the assessments which lacked dates to the injuries. Where an assessment did not exist for the time of the incident, the result of the oldest assessment was used instead.

5.1.1.3 Data of Assembly Errors

The data from the ATACQ system concerning the quality of assembly errors was merged together with the data of ErgoRAV assessments and work injuries. When all data was collected it was possible to start analyzing and look for whether correlations existed or not.

5.1.2 Data Analysis

In this subsection, the quantitative data will be analyzed and compared to find correlations between the data sets. An overall analysis of the assembly plant will be followed by an in-depth analysis of the different PVC areas. Note that the PVC area *Area F* will not be analyzed further since it had no red ErgoRAVs and no reported injuries in 2018. *Area F* is also different as it mainly consists of small quality control stations at the end of each assembly line. Though, it will still be included in the analysis of the whole assembly plant. For confidentiality reasons, the numbers and values are multiplied with random factors. Therefore, does the presented values not correspond to the reality.

5.1.2.1 Assembly Plant Analysis

To find correlations between ErgoRAV assessment and work injuries it was necessary to process the data before importing it for analysis in JMP. Since the reports in TIA did not include what station the injury occurred on, the average share of red ErgoRAVs were calculated for each department. To get as accurate results as possible, the ErgoRAV assessments performed closest before the event was extracted from the version history in SharePoint. If no ErgoRAV assessments existed in the SharePoint prior to the time of the injury, the result of the most recent ErgoRAV assessment was used.

Since the different departments have a varying number of stations, the amount of work injuries at the departments does not tell the whole story as departments with many stations will have many injuries. Therefore, the number of injuries of the department was divided by the number of stations at that department. An example of how this proportional distribution looks is presented in Table 5.1.

Table 5.1: Injuries and red ErgoRAVs on department level and work injuries per station. *The displayed figures are fictive and do not represent the reality in VCT.

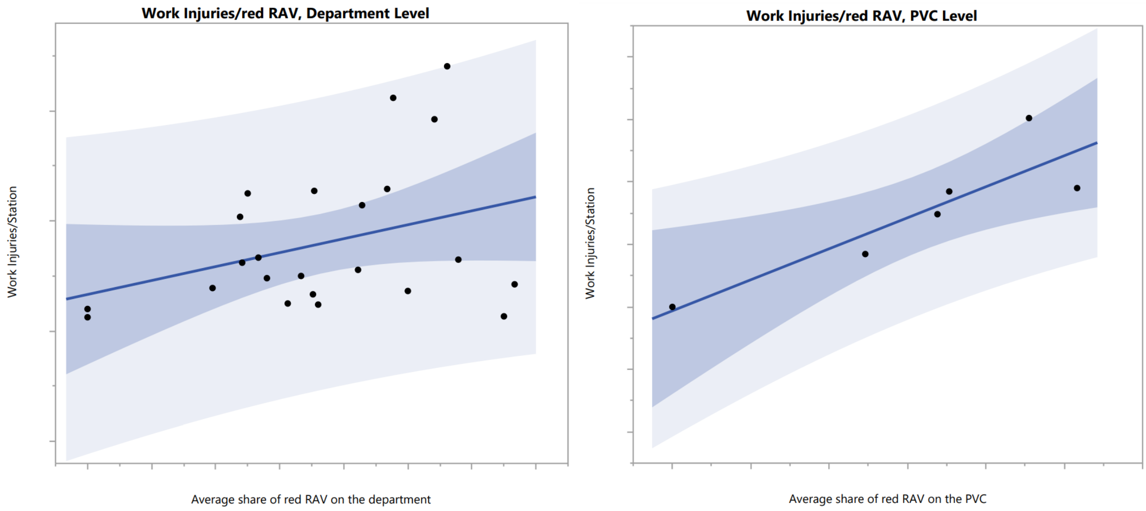
Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station
Department D1	5	0,27	0,03
Department D2	63	0,23	0,4
Department D3	13	0,18	0,12
Department D4	8	0,15	0,07

This table was used to calculate the same numbers for the whole PVC areas. The resulting distribution can be seen in Table 5.2 below.

Table 5.2: Average share of red ErgoRAVs and work injuries per station in each PVC area.

PVC Area	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station
Area A	203	0,19	0,25
Area B	90	0,14	0,13
Area C	85	0,15	0,15
Area D	88	0,22	0,38
Area E	28	0,10	0,16
Area F	0	0,00	0,00

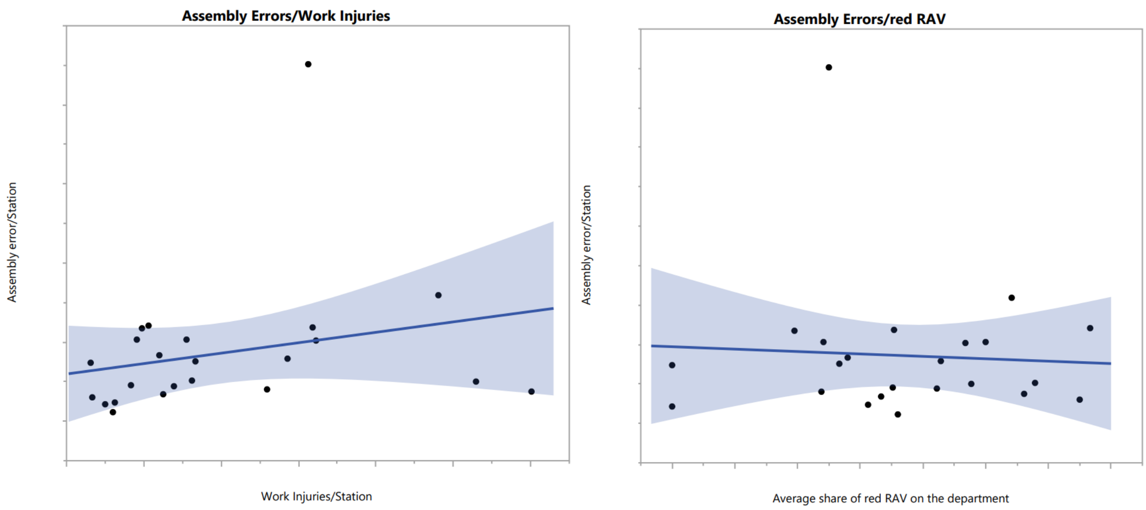
The average share of red ErgoRAVs and work injuries per station are visualized in Figure 5.1. The dots in the figure represent each the number of injuries/station and the average share of red ErgoRAVs and the blue line represents a function that models the relationship between the two variables. The dark blue area represents the confidence region for the fitted line and the light blue area represents the confidence region for individual predicted values. The Pearson product-moment correlation between the work injuries/station and the share of red ErgoRAVs was calculated to 0,35 on department level and 0,88 on PVC level. From this, the conclusion can be drawn that there exists correlation between the ErgoRAV results and the work injuries. This means that if there are more red ErgoRAVs in the department, there will be more work injuries in that department. In the graph on the PVC level, the noise is reduced with the average and therefore the data points stays closer to the fitted line. An interesting behavior in the graph on department level is that some data points indicate that the number of injuries does not increase when the number of red ErgoRAVs increase. This was investigated further and is presented in subsection 5.1.3.



(a) Department level **(b)** PVC level

Figure 5.1: Share of red ErgoRAVs compared to work injuries per station.

To investigate if bad ergonomic conditions affect the quality of the assembly work, the number of assembly errors were compared to work injuries which are presented in Figure 5.2a. In this graph, it can be seen that there might be a connection between the two parameters. The graph shows that if the number of injuries on a department is higher, there is an increased probability for an increase in the number of assembly errors in that department. The same trend cannot be seen when the assembly errors are compared to the share of red ErgoRAVs in Figure 5.2b.



(a) Assembly errors vs. work injuries. **(b)** Assembly error vs. red ErgoRAV.

Figure 5.2: Assembly errors compared to work injuries and red ErgoRAVs.

PVC: Area A

Area A is the PVC area with the highest amount of work injuries per station. In 2018, out of all work injuries in the category musculoskeletal disorders that were reported in the *Area A*, 28 % of those were reported in *Department A4*. This department also had the highest number of work injuries per station with 0.5 injuries/station. This is also the highest number in the whole assembly plant. The ErgoRAVs on *Department A4* have 56% red results. This is lower than for *Department A2* where 58% of the ErgoRAV are red. Notably *Department A2* only had 12 work injuries with 0.13 injuries/station. *Department A5* had the second highest number of work injuries per station in the whole assembly plant with 0.44 injuries/station. In Table 5.3 below, the full results for *Area A* are presented.

Table 5.3: Data on PVC area: *Area A*.

Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department A1	20	0,18	0,24	0,08
Department A2	30	0,24	0,13	0,05
Department A3	15	0,10	0,1	0,08
Department A4	58	0,23	0,5	0,03
Department A5	45	0,2	0,44	0,05

PVC: Area B

Area B is the PVC area with the second lowest amount of injuries and share of red ErgoRAVs. Although, it also has the department with the highest share of red ErgoRAVs. *Area B* has 67% red ErgoRAVs which is the highest in the assembly plant. This is not at all reflected in the number of injuries that occurred in that department. In 2018, very few injuries were reported in this area which results in this area being the bottom 8 in the assembly plant. The department with the highest number of work injuries per station in the *Area B* is *Department B2*. *Department B2* has the second lowest number of red ErgoRAVs in this PVC area. In Table 5.4 below, the full results for *Area B* are presented.

Table 5.4: Data on PVC area: *Area B*.

Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department B1	25	0,11	0,14	0,07
Department B2	35	0,1	0,22	0,04
Department B3	15	0,14	0,10	0,03
Department B4	18	0,28	0,09	0,11
Department B5	20	0,08	0,08	0,11

PVC: Area C

The PVC area *Area C* had a moderate amount of work injuries per station in 2018. The average share of red RAVs where 35.6% when the injuries where reported. *Area C* has one department that stands out in terms of red RAVs compared to reported injuries and that is department *Department C4*. It is in the top 6 highest shares of red RAV's in the assembly plant but is bottom six of the departments in amount of reported injuries. The departments *Department C1* and *Department C2* are both in the top five of most reported injuries per station in 2018, with 0.27 reported work injuries/station. In Table 5.5 below, the full results for *Area C* are presented.

Table 5.5: Data on PVC area: *Area C*.

Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department C1	35	0,15	0,27	0,11
Department C2	50	0,20	0,27	0,10
Department C3	23	0,1	0,13	0,10
Department C4	10	0,21	0,08	0,10
Department C5	3	0,00	0,04	0,02

PVC: Area D

Area D has the largest share of red ErgoRAVs in the assembly plant with an average of 51.6%. It had the second most reported injuries per station in 2018. *Area D* includes two departments that are almost exactly similar. This is also shown on the share of red ErgoRAVs and number of reported injuries. *Area D* also includes the department *Department D1* and *Department D2* which both are in the top 5 of highest numbers of red ErgoRAVs in the assembly plant. *Department D2* had the third highest number of reported injuries/station in 2018, which reflects on the number of red ErgoRAVs. The most interesting result from this PVC area is the results for department *Department D1*. It has the second most share of red ErgoRAVs but this was not at all reflected on the number of reported injuries in 2018 where only two injuries were found in the TIA database. This result gives it very close to the bottom. The cause of this result was investigated in the following sections. In Table 5.6 below, the full results for *Area D* are presented.

Table 5.6: Data on PVC area: *Area D*.

Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department D1	5	0,27	0,03	0,03
Department D2	63	0,23	0,4	0,15
Department D3	13	0,18	0,12	0,00
Department D4	8	0,15	0,07	0,04

PVC: Area E

The PVC area *Area E* has the lowest share of red ErgoRAVs and had the lowest amount of reported injuries per station in 2018. The departments that stand out in this PVC area is department *Department E2* with 0.27 injuries per station and only 25% red ErgoRAVs. So a high number of injuries and a low number of red ErgoRAVs. Important to note is that department *Department E2* have a few amount stations, which makes the results more influenceable by random events. In Table 5.7 below, the full results for *Area E* are presented.

Table 5.7: Data on PVC area: *Area E*.

Department	Number of Work Injuries	Average Share of Red ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department E1	3	0,00	0,03	0,07
Department E2	13	0,10	0,27	0,42
Department E3	8	0,15	0,05	0,01
Department E4	5	0,13	0,05	0,02

5.1.3 Conclusion of Data Analysis

In this section, the departments with deviating results were further investigated, i.e. where the result of the ErgoRAV assessment does not match the number of reported injuries. Four departments were chosen to investigate further with qualitative data collection in the form of interviews. The chosen departments and the reason for the choice can be seen in 5.8.

Table 5.8: ErgoRAV, injuries and quality data on PVC area: Departments that do/do not correlate

Department	Reason for investigation	Average Share of RED ErgoRAVs	Work Injuries/Station	Quality errors made by operators/station
Department A5	Low share of red ErgoRAVs compared to reported injuries.	0,48	0,44	0,46
Department A4	Low share of red ErgoRAVs compared to reported injuries.	0,56	0,5	0,03
Department D1	High share of red ErgoRAVs compared to reported injuries.	0,65	0,03	0,03
Department D2	Low share of red ErgoRAVs compared to reported injuries.	0,54	0,4	0,15

The conclusion from the quantitative data analysis and further investigation is that the RAV results correlate with the work injuries on a holistic level. This conclusion can be drawn from the injury data on PVC level that correlates well with the average share of red ErgoRAVs. However, since the TIA reporting procedures differ between the departments, it is impossible to conclude if the ErgoRAV functions well on certain departments from the quantitative data analysis. Since only data from 2018 is available, the population was not good enough to draw any conclusions from the department level analysis.

5.1.4 Qualitative Data Collection

Qualitative data was collected through interviews with employees at VCT and Health & Safety, which are affected by the ErgoRAV.

Interviews were performed with different stakeholders, people whose work are concerned by the ErgoRAV including safety delegate members, production leaders, ergonomists, Health & Safety specialist, and industrial engineers. All interviews were semi-structured and the results from these will be presented in this section. Interviews with the production leaders also included questions concerning incident reporting, apart from questions regarding the ErgoRAV which were asked to all parties. All interview questions can be found in 3.1.4. In Table 5.9 below, a list of all interviewees is presented.

Table 5.9: List of interviewees

Interviewee	Gender
Production leader 1	F
Production leader 2	F
Production leader 3	F
Production leader 4	M
Union representative 1	F
Union representative 2	M
Union representative 3	M
Production engineer 1	M
Production engineer 2	M
Production engineer 3	M
Health and Safety representative	M

The production leaders for the departments in Table 5.8 were interviewed with the purpose to find the reason for the deviating results. All the departments investigated had, according to the production leaders, high operator turnover. This could mean that injuries do not occur in the same department as where the cause of the injury can be found. The production leaders at the department *Department D1* also mentioned that the number of work injuries was high, which was not reflected in the TIA database. This suggests that the reporting process differs from department to department and therefore it is difficult to draw any conclusions about results from the RAV tool. Some of the production leaders report the injuries immediately when the operator mentions it, and others try countermeasures and report them into the TIA database if the condition does not improve over time.

The ErgoRAV affects each stakeholder in different ways, some are more affected by the result the ErgoRAV gives, and some on how the ErgoRAV is performed. The results of the ErgoRAV has the purpose to provide guidelines for resource allocation, where red ErgoRAVs indicate that resources need to be provided. The purpose of the ErgoRAV is mainly said to inform as early as possible where there are risks in order to reduce musculoskeletal disorders at the assembly line.

When asked the question *"Do you trust the results that the ErgoRAV provide?"* all interviewees hesitated and then answered yes. According to multiple interviewees, if the same question would have been asked a few years ago the answer would probably be different, lots of work has been put into the ErgoRAV in the last years which has increased the trustability. The RAV teams comprise more members with broader competence and more time is put into performing the assessments. Uncertainties also existed regarding the results depending on what RAV team that performed the ErgoRAV, it was said that some teams are more detailed than others when assessing. If the RAV team is competent and interprets the questions well, the result is interpreted as trustworthy.

In order to make improvements in the assembly plant, the production needs to be rated green ergonomically. When an ErgoRAV is red, a countermeasure is produced with the purpose to turn the ErgoRAV result of the station into green. The reality is that the result often changes before the method is thoroughly implemented. It should not be possible to judge if the result should be turned into green before the methods are fully implemented.

Ergonomists from the outside corporate health care organization Feelgood perform assessments when requested from the production leader or the industrial engineer. Calibrations between the ergonomists are performed four times a year. At these meetings, Health & Safety together with the ergonomists go through different assessments in a group and discuss the results to ensure that the assessments are based on similar reasoning. They also talked about improvement areas of the ErgoRAV. The interaction between ergonomists and ErgoRAV is perceived as relatively good. Production leaders and industrial engineers analyze the ergonomic assessments and, since they are familiar with the station and the problems they have there, they can see if the ergonomic assessments have deficiencies. If that is the case, they ask for another additional assessment. They would like to see that the ergonomists work is performed in a more standardized way. Today all ergonomists perform assessments based on different methods combined with their own knowledge but since the turnaround of ergonomists is high, it can be hard to create a standardized way of working. Some assessments include more information than others and differs depending on who was performing the assessment. These differences affect the trustworthiness of the ergonomists since it is perceived that some are more detailed than others in their assessments.

The general perception of the ErgoRAV is that it is intricate and complex. The purpose of the ErgoRAV is, for most people, unknown. The perception is affected by the experience of the operator, where experienced operators know more about the purpose. Operators in general need to be enlightened with the purpose of the ErgoRAV. When asking random operators in the assembly plant if they recognized the ErgoRAV most people answered yes and pointed to the location where the RAV was visual at their station. That was about as far as the knowledge regarding the

RAV extended as there was no clear knowledge of the aim and purpose of the RAV.

It was also mentioned by multiple production leaders that plenty of ErgoRAVs resulted in red because the operator did not work according to the recommendations. This was mainly because there was no knowledge that work instructions existed. There are work instructions on all stations at VCT and all operators are assigned to go through these, together with other instructions, when being employed. They also need to sign that they have gone through, read and understood the informative instructions. Also, when changes are made, everybody needs to sign that they have been informed and read through the changes. This should result in them knowing how to work according to instructions on their station. But this seems to not be the case. This can be because of in-explicit instructions or simply that the operator has not studied them. Operators not working according to recommendations/instructions is a big contributor to musculoskeletal disorders.

Mentioned shortcomings of the ErgoRAV from the interviews:

- The questions in the ErgoRAV are open for interpretation and the user can affect the result.
- Clarity regarding frequency is missing.
- Standardized information regarding visualization of the ErgoRAV is missing.
- The tool should be easier to use.
- Lack of visualization to describe the questions.
- No visualization on the cover page to inform about ergonomic risk areas.
- Lack of knowledge concerning work instructions on the assembly line.
- The ErgoRAV only evaluates stations and not rotations.

5.1.5 Summarizing the Current State

Connections between quantitative and qualitative data were difficult to find since the information in the TIA database probably did not convincingly reflect the number of actual work injuries on the department level. The data is affected by the individuals that report the injuries into the database and it is therefore impossible to tell what the root cause for the deviation is. What can be interpreted from the data compared to the interviews, is that the ErgoRAV successfully identifies stations that have bad ergonomic conditions. The injury data on the PVC level correlates with the average share of red ErgoRAVs, and the stakeholders mention that they mostly trust the results that the RAV delivers. Summary of the current state of the ErgoRAV in bullet points:

- On a high level there exists a correlation between injuries and red ErgoRAVs.
- The data does not reveal the reason for the missing correlation at some departments.
- The ErgoRAV should function as a screening tool, and not a complete ergonomic evaluation. It should therefore rather over-assess risks rather than understate them.
- The reason that the ErgoRAV is currently trusted, is that the RAV teams are improving and getting more synchronized. Although, there exists mistrust from various stakeholders.
- The questions in the current ErgoRAV are hard to interpret and the user affects the results to a high extent.
- There is a lack of knowledge regarding the work instructions on the stations at the assembly line which results in red ErgoRAVs and risks for the operator of not working as recommended.
- Split opinions on if subjective parts should be included.
- The current ErgoRAV does not assess rotations, which is perceived as an issue.

5.2 Improvements to the ErgoRAV

With the results from the quantitative and qualitative study, conclusions can be drawn on what improvements of the ErgoRAV should be made. All of which is used to create a new requirement specification in order to create new concepts, which later are to be verified. It is important to highlight that the new ErgoRAV generated is to be performed by what today is defined as the RAV team. Meaning that the questions are made with the consideration that a production leader, safety delegate member, industrial engineer, and an operator are intended to answer them.

The ErgoRAV needs to include categories which capture all risks contributing to musculoskeletal disorders. To make sure all areas are included, regulations from the Swedish Work Environment Authority, the VCC ergonomic standard, and opinions from the stakeholders are taken into consideration when establishing the requirements.

5.2.1 Requirements from Regulations and Standards

The requirement from the Swedish Work Environment Authority regarding ergonomics for the prevention of musculoskeletal disorders, AFS 2012:2, has a checklist which can be used to assess risks. In this checklist, all questions which were relevant for this case was taken out and listed. The questions remaining were then grouped into six categories:

- Work postures and working movements
- Work environment and individual adaptation
- Visual conditions and placement of equipment
- Lifting aids and work technique
- Grips, handles, and controls of hand tools and equipment
- Work variation and recovery

A comparison between AFS 2012:2 checklist and VCC ergonomic standard were created to help visualize the process as clearly as possible. This visualization was created for each of these categories and will be presented in the following subsections in Figures 5.3, 5.4, 5.5, 5.6, 5.7, and 5.8. The column to the left represent all questions from the AFS 2012:2 checklist within the category. The column to the right represent statements from the VCC ergonomic standard within the category. Arrows were drawn between the two columns in order to see where the VCC ergonomic standard answered the questions from the checklist. This also made it visible to see areas where the VCC ergonomic standard was more specified than the checklist. Boxes were colorized with the purpose to clarify in which areas the VCC ergonomic standard was inadequate or more elucidative than the checklist:

- Yellow marked boxes are questions which the standard fails to bring up.
- Grey marked boxes are statements that are more specified than what AFS 2012:2 checklist requires.

- White marked boxes are questions and statements where the two answer to each other.

Areas in the checklist which are not identified in the VCC ergonomic standard needs to be reinforced by complementary literature and well-tested methods before being included in the ErgoRAV.

Work Postures and Working Movements
The first category concerns work postures and working movements. The questions from the AFS 2012:2 checklist and the statements from the VCC ergonomic standard related to this category are shown in Figure 5.3. There are several points from the AFS 2012:2 checklist that are not treated in the VCC ergonomic standard. Neither assessment of lifting or pushing/pulling are defined with respect to all the factors highlighted in the checklist. The standard also does not put any requirement to avoid kneeling, crouching and work in the supine position. It also does not mention anything about flexing and twisting of arm and wrist.

The standard has a few points with requirements that are more comprehensive or supplemental to the checklist. The checklist does not cover the specific force requirements that the ergonomic standard comprises. These demands are set by VCC and include allowed pressure forces and the shape of the area where force is to be applied [26]. The AFS 2012:2 also does not specifically give a number on how large share of the workday the operator should work in ergonomically correct work postures, which the standard does.

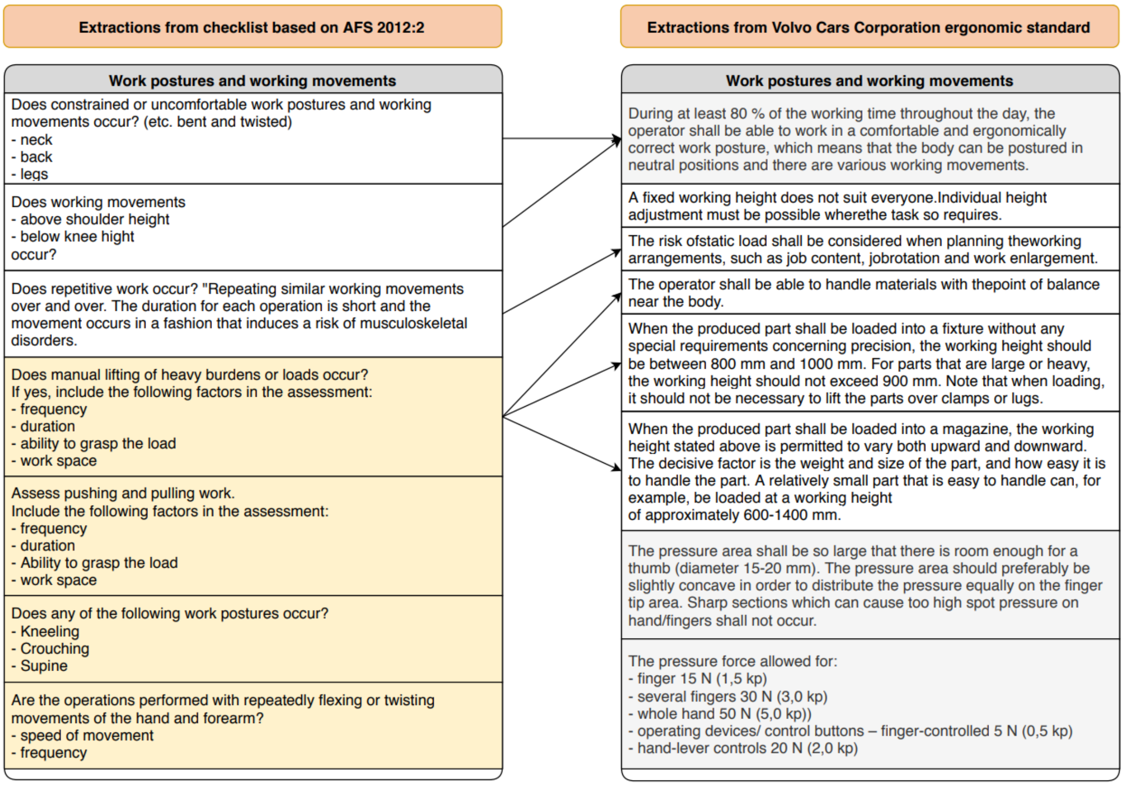


Figure 5.3: Flowchart of the category work postures and working movements

Work Environment and Individual Adaptation

The second category concerns work environment and individual adaption and the questions and statements related to this category are shown in Figure 5.4. The AFS 2012:2 checklist brings up whether there is an adequate room or not to perform given working movements meaning that the workplace should be designed for small operators to reach as well as a large operator [27]. A good working condition according to VCC ergonomic standard has physical freedom of movement together with a possibility of variation with respect to work content and movement pattern [26]. Since it is not explained further what adequate room is in the VCC ergonomic standard this question is marked as yellow. The other questions in this category are captured in the VCC ergonomic standard, questions regarding adaptable working heights, placement of equipment and work objects.

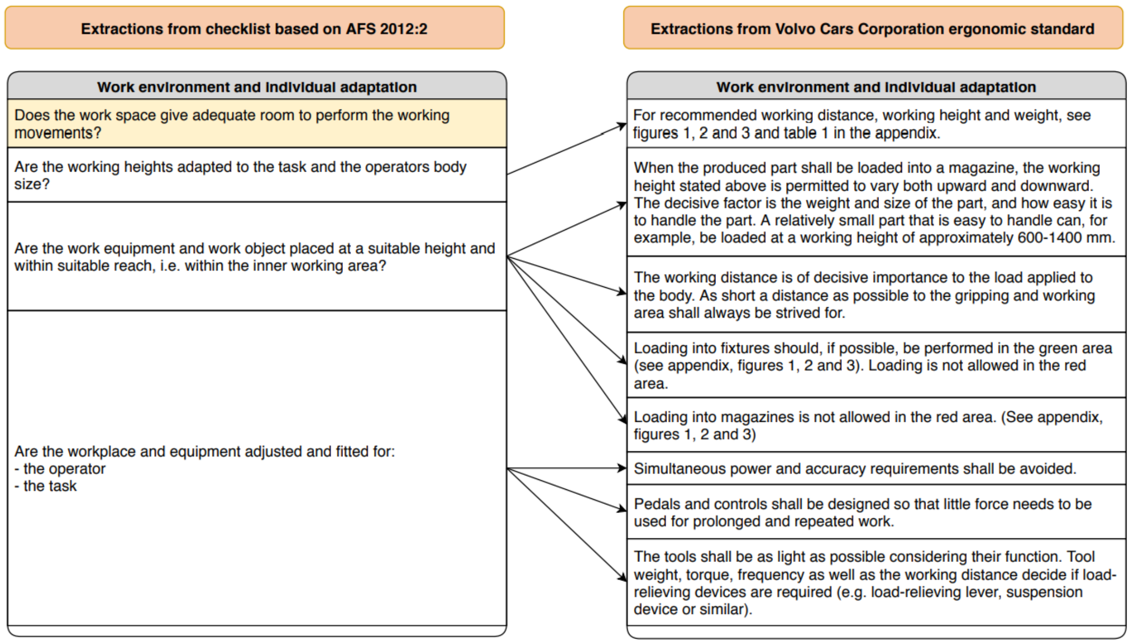


Figure 5.4: Comparison of category work environment and individual adaptation

Visual Conditions and Placement of Equipment

The third category represents visual conditions and placement of equipment and can be seen in Figure 5.5. It is important to be able to see the work object for reducing the risks of accidents and musculoskeletal disorders [27]. The VCC ergonomic standard answers well to this matter, it is stated that the accessibility and field of vision must not be restricted and that hidden assembly without a guide should not be used [26].

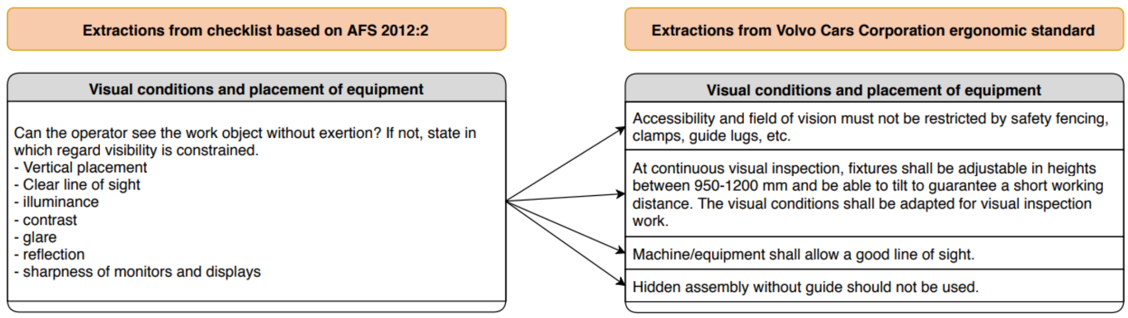


Figure 5.5: Comparison of the category visual conditions and placement of equipment

Lifting Aids and Work Technique

The fourth category is lifting aids and work technique, and is presented in Figure 5.6. The AFS 2012:2 checklist asks questions regarding the use of lifting aids and if the operator possesses knowledge on how to properly use the lifting aids and uses the correct work technique in general. In this matter, the VCC ergonomic standard highlights who is responsible for investigating if lifting aids is to be used, that the operators who are to use the lifting aid needs to have gone through training [26].

The VCC ergonomic standard exaggerates areas in where the AFS 2012:2 checklist does not bring up, areas dealing with packaging and how this area always should be designed for use with devices such as lifting aids [26]. The question concerning this area is therefore marked as grey.

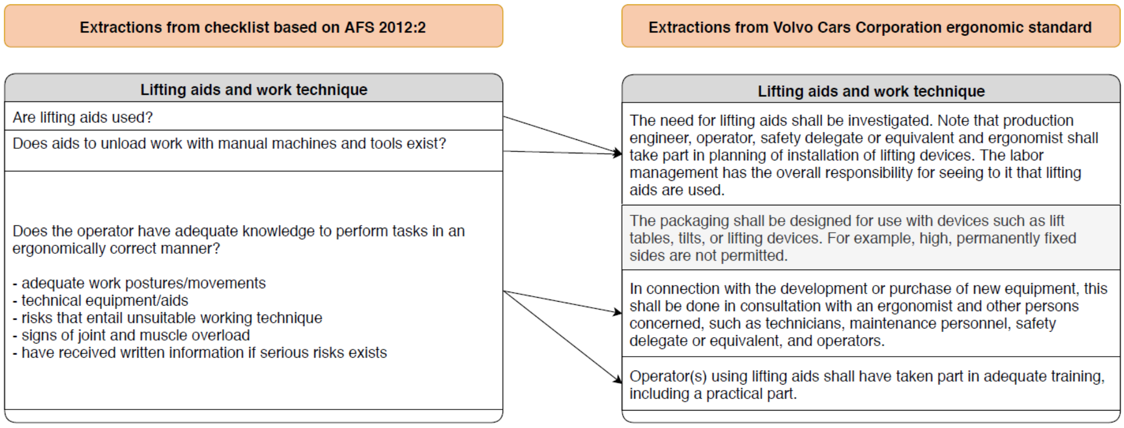


Figure 5.6: Comparison of the category lifting aids and work technique

Grips, Handles, and Controls of Hand Tools and Equipment

The fifth category, grips, handles, and controls of hand tools and equipment is compared in Figure 5.7. This category is well comprehensive in the VCC ergonomic standard including recommended values for handgrip pressure forces, grip/handle length and exposure values for vibration. It also cover areas regarding the material of the grips, balancing of the tool, and maneuver and accessibility of controls [26].

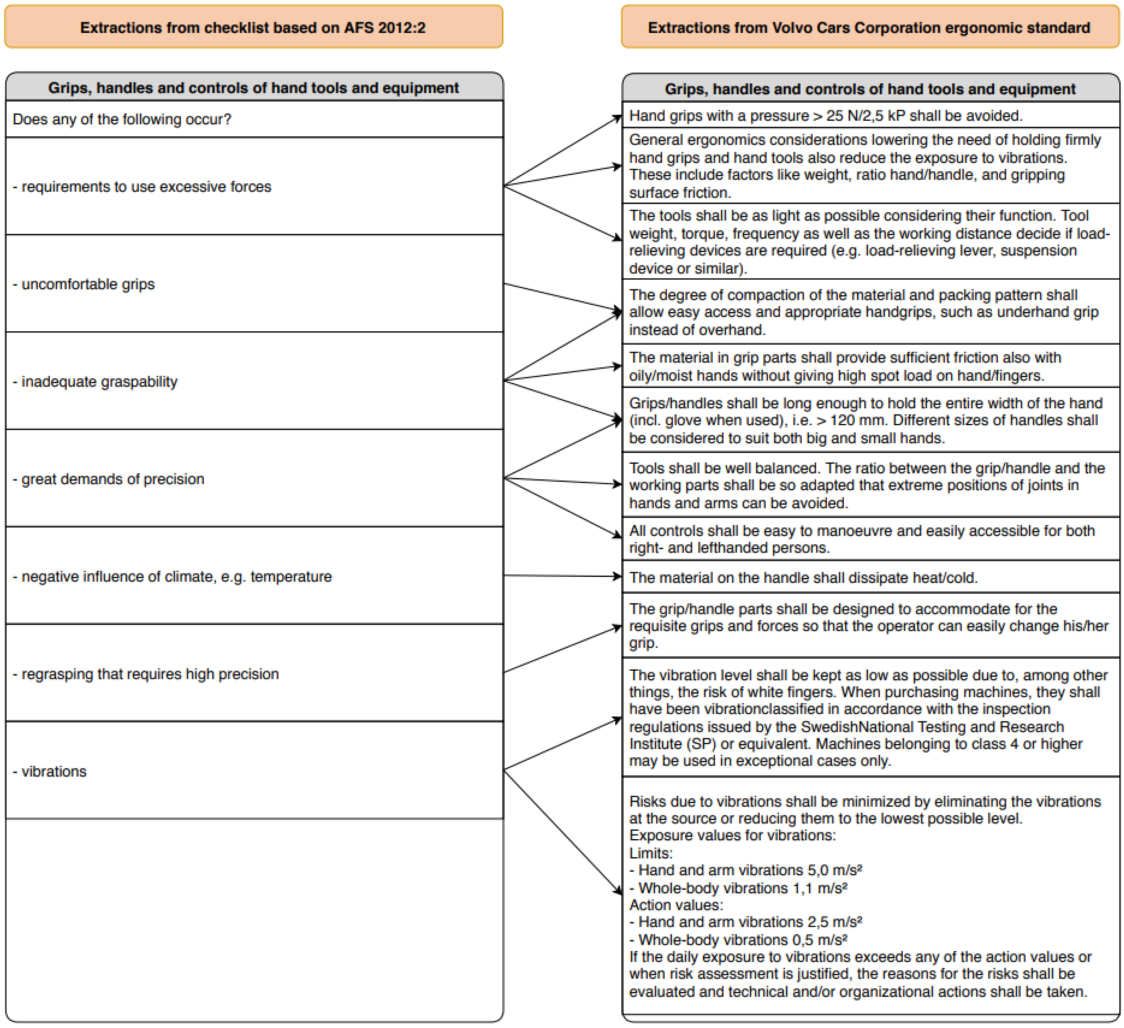


Figure 5.7: Comparison of the category grips, handles and controls of hand tools and equipment

Work Variation and Recovery

The sixth category concerns work variation and recovery, and the comparison between AFS 2012:2 checklist and VCC ergonomic standard is shown in Figure 5.8. The AFS 2012:2 checklist only asks if the operators have the possibility to get adequate recovery by influencing their work. The VCC ergonomic standard does further clarify this point by making additional requirements on variation, job rotation, work enlargement, and the possbility to control your work.

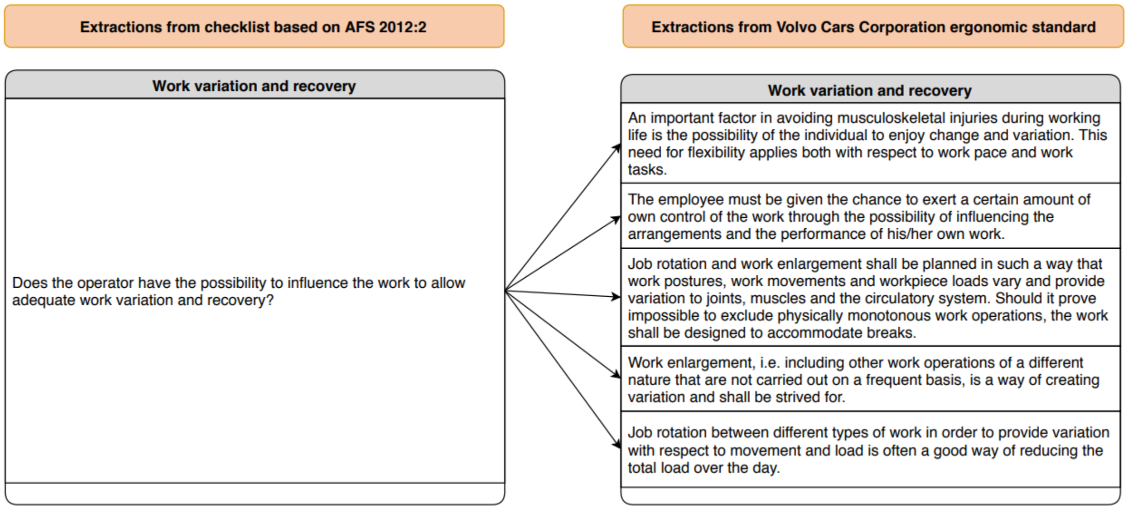


Figure 5.8: Comparison of the category work variation and recovery

5.2.2 Requirements from Stakeholders

As previously concluded from the interviews, the stakeholders require the following for the ErgoRAV:

- The design of the RAV can be improved by changing into a standardized look throughout the RAV.
- Possibilities to assess rotations with the ErgoRAV.
- Add visualization to clarify the ErgoRAV questions.
- Clarify assessment regarding frequency.
- Change question layout so that they are not open for interpretation.
- Larger response scale in the form of green, yellow, and red.

All in which will be considered when generating concepts.

5.3 Concept Generation of the Improvements

In this section, the process of generating the new ErgoRAV will be presented. The process of creating the assessment of the individual stations will be followed by the process of creating a tool for assessment of rotations. The goal was to generate concepts with a design matching the VCC standard documents that had built-in functions, see the design of the new cover sheet in Appendix A.1. The purpose of this was to make it easy to use. The concepts were created in Microsoft Excel where Microsoft Visual Basic for Applications was used to program the functionalities, all necessary calculations, behind all questions. The process of presenting the generated questions, and how to present them, will here be described step by step. The process of verifying the concepts is also described.

5.3.1 Assessment of Individual Stations

The flowcharts presented in section 5.2.1 has the end purpose to highlight areas which need to be included in the ErgoRAV. The result will, therefore, be an ErgoRAV that answers to the requirements from the Swedish Work Environment Authority, the VCC ergonomic standard, and the preferences from the stakeholders. Categories which concerns frequency, duration, and what type of force exertion is used, needs further information. This information will be generated through well tested ergonomic methods. The methods that were primarily used was methods recommended by the Swedish Work Environment Authority which was highly appreciated by VCC and the union. These methods were KIM-LHC and KIM-MHO.

KIM-LHC is recommended to be used for tasks including lifting, holding and carrying where the weight of the load exceeds 5 kgs. This might be suitable for tasks that include logistics or assembly tasks that lack lifting aids. But, at the assembly line in Torslanda, most of the work does not include heavy lifting, holding or carrying. Therefore KIM-MHO is the more suitable method to assess the ergonomics in the assembly plant. KIM-MHO also creates the possibility to assess rotations, which was a requirement from the stakeholders.

There was a request from the stakeholders that they did not want any calculations to be included in the ErgoRAV, only yes/no questions. The reason for this was that they thought it would be perceived as difficult to use and too complex. In order to generate as good, and reliable a result as possible, without asking too many questions, a conclusion was made that there is a need to perform calculations. The solution made to satisfy both parts was to use calculations which automatically generate results when yes/no questions are answered.

The following sections will present the questions that were generated within each category presented in section 5.2.1.

Work Postures and Working Movements
The questions generated in this category were:

- Enter what force level is used, how many times/how long per station the posture is performed. Fill no more than three postures and use values between 0-60. (including additional visualization)
- In what positions do hand/arm movements occur? (including additional visualization)

It is mentioned in the VCC ergonomic standard that at least 80 % of the working time needs to be in a comfortable and ergonomically correct posture. Other than that there are no further restrictions on how long or how many times an operator can perform a task. KIM-MHO uses calculations to generate rated points for different areas. The area which concerns postures is divided into four categories with different rating points. In order to simplify the assessment and to personalize it for VCT pictures were taken of the operators in the assembly plant. From the pictures, visualizations were made and used in the ErgoRAV. The rated points for the chosen postures are automatically generated when the user enters data for that posture. See the visualizations in Figure 5.9. A takt time of 60 seconds was used throughout the ErgoRAV.

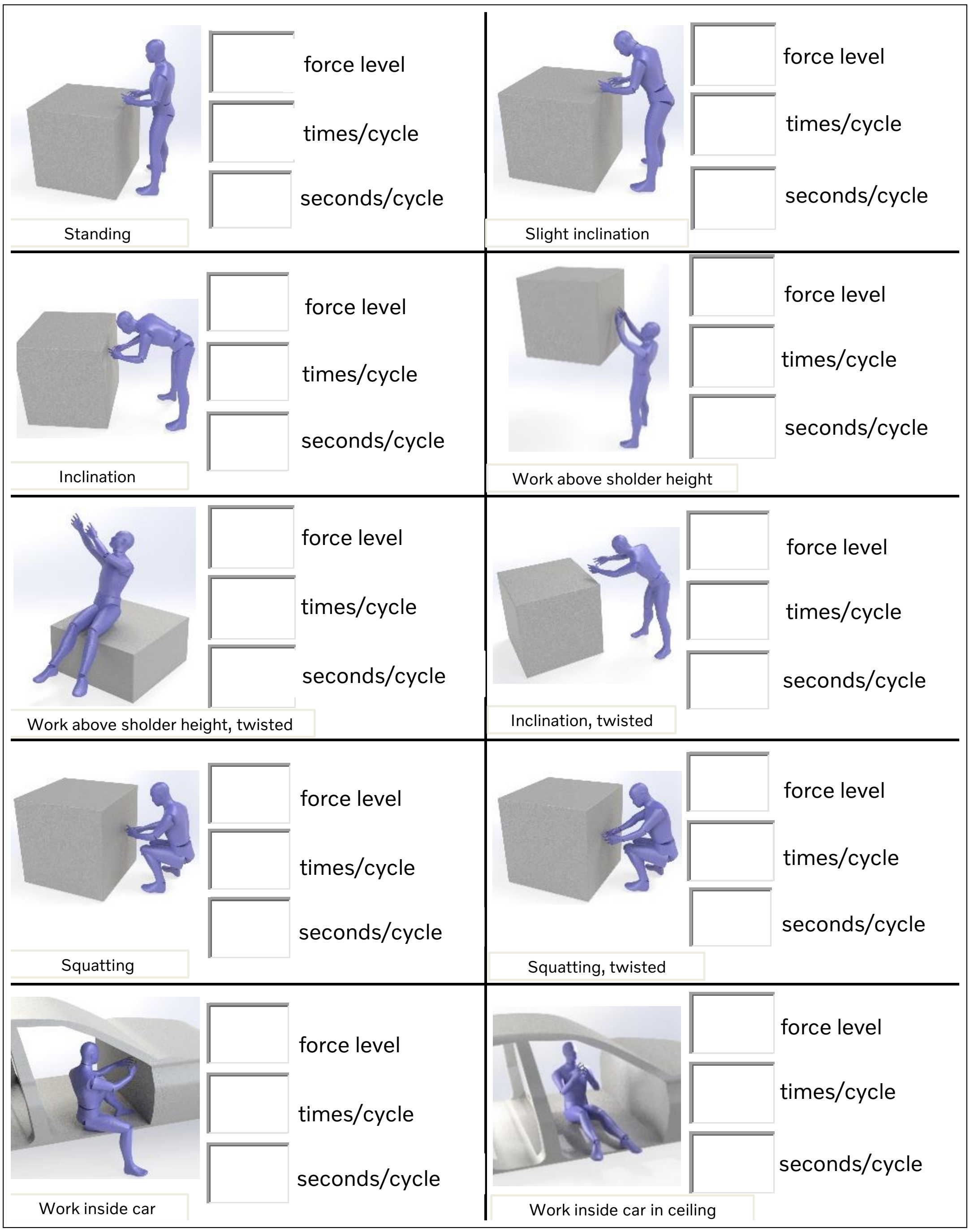


Figure 5.9: Visualization of the work postures and working movements

The four categories, descriptions and rated points concerning postures [18] can be seen below in table 5.10.

Table 5.10: KIM-MHO posture description and rated points

Classification	Description	Rated points
Good	Alternation of sitting and standing is possible/alternation of standing and walking/dynamic sitting is possible/hand-arm rest possible as required/no twisting/head posture variable/no gripping above shoulder height	0
Restricted	Trunk with slight inclination of the body towards the area of action/predominant sitting with occasional standing or walking/occasional gripping above shoulder height	1
Unfavourable	Trunk clearly inclined forward and/or twisted / head posture for detail recognition specified/restricted freedom of movement/exclusive standing without walking/frequent gripping above shoulder height/frequent gripping at a distance from the body	3
Poor	Trunk severely twisted and inclined forward/body posture strictly fixed/visual check of action through magnifying glasses or microscopes/severe inclination or twisting of the head/frequent bending/constant gripping above shoulder height/constant gripping at a distance from the body	5

There are ten different postures to choose from in the ErgoRAV. All rated points from the postures which are chosen (maximum three and minimum one) need to be weighted depending on how long and how many times the operator is exposed to that posture. The postures which are not chosen does not get assigned any value. If the operator is exposed for a short time it makes sense that the rated point should not be the same as when exposed for a longer time. All weighted rated points are summed and later used in the final calculation in section 5.3.2. The calculation for the weighted rated points for the postures are:

$$Wr_{Posture} = \sum_{n=1}^{12} \frac{P_{Posture}}{60} * t_{Exposed} * r_{Exposed}$$

where:

$Wr_{Posture}$: Weighted result for the postures
n : Number of postures
$P_{Posture}$: Rated points for the postures
$t_{Exposed}$: the time, in seconds, the operator is being exposed
$r_{Exposed}$: the number of repetitions performed by the operator

There are three assigned values next to the exposed postures, force level, frequency, and duration. KIM-MHO defines seven different types of force levels concerning force exertions in the finger-hand area. All seven levels have different assigned values which are used when calculating the rated points for the force exertion area. The force levels for the force exertions in the finger-hand area are [18] see Table 5.11.

Table 5.11: KIM-MHO force exertions levels in the finger-hand area

Classification	Description	Force constant
Very low forces	E.g. button actuation/shifting/ordering	1
Low force	E.g. material guidance/insertion	1,6
Moderate forces	E.g. gripping/joining small work pieces by hand or with small tools	2,5
High forces	E.g. turning/winding/packaging/grasping/holding or joining parts/pressing in/cutting/Working with small powered hand tools	4
Very high forces	E.g. cutting involving major element of force/-working with small staple guns/moving or holding parts or tools	6,3
Peak forces	E.g. tightening, loosening bolts/separating/pressing in	10
Hitting	With ball of the thumb, palm of the hand or fist	6,3

The rated points for the force exertions in the finger-hand area are then calculated through the following equation [32]:

$$P_{Force\,exertion} = \sum_{n=1}^{3} 2,5 * f * \frac{t_{Exposed}}{60} + \sum_{n=1}^{3} 2,5 * f * \frac{r_{Exposed}}{60}$$

where:

$P_{Force\,exertion}$: Rated points for the force exertions
n : Number of selected postures
f : Force constant
$t_{Exposed}$: The time, in seconds, the operator is being exposed
$r_{Exposed}$: The number of repetitions performed by the operator

The time of which the operator is exposed to the assigned positions is summed and assumptions are made that the remaining time is the time where the operator works with minimum force exertions. The calculation below provides the rated points for a situation where the operator works with minimum force exertions in the finger-hand area (force level = 1):

$$P_{Time\,left} = 2,5 * 1 * \frac{60 - t_{Total}}{60}$$

where:

$P_{Time\,left}$: Rated points for the time left
t_{Total} : The total time, in seconds, the operator is being exposed

The whole station is to be assessed so the rated points for the force exertions in the finger-hand area, for both the exposed time and the non-exposed time, are summed. This value is used when calculating the final calculation in section 5.3.2.

KIM-MHO also has rating points for hand/arm positions and movements. Visualization for this area are similar to the visualizations for the area concerning postures, see Figure 5.10. See the different categories and their rated points taken from KIM-MHO [18] in Table 5.12.

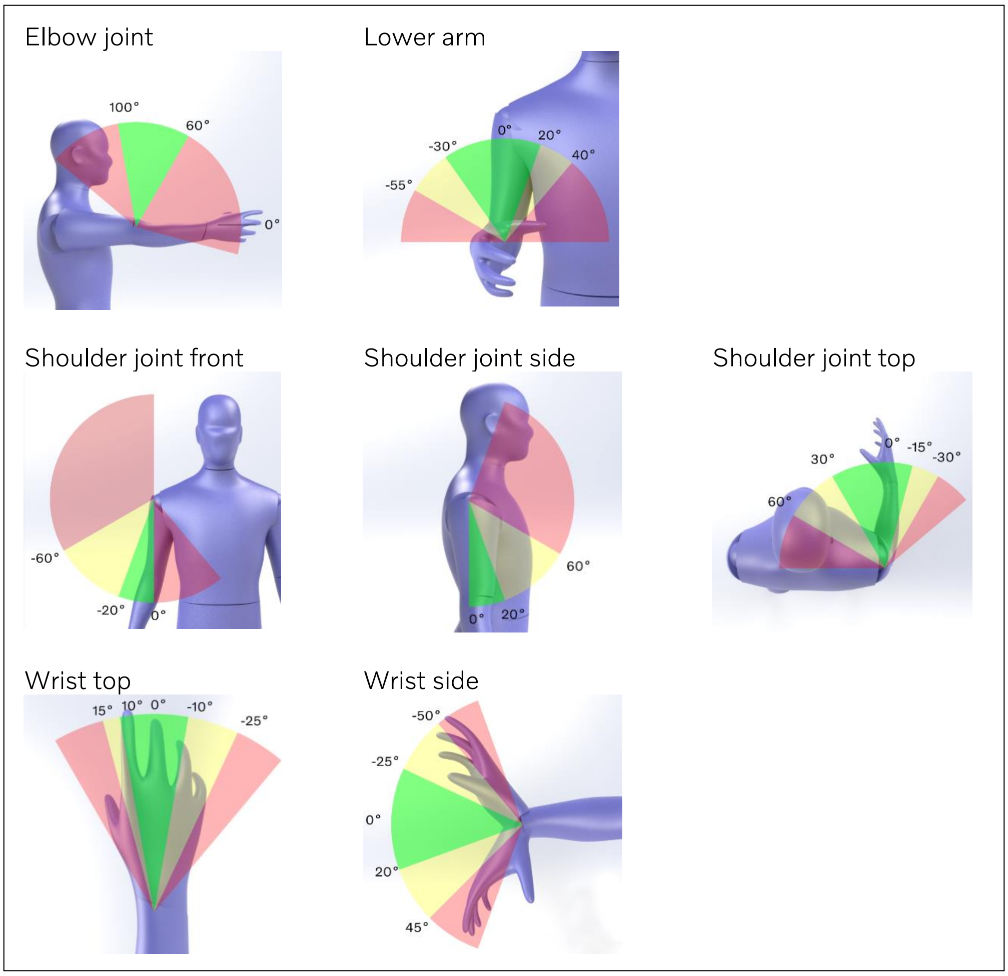


Figure 5.10: Visualization of hand/arm positions and movements

Table 5.12: KIM-MHO hand/arm posture and movement description and rated points

Classification	Description	Rated points
Good	Position or movements of joints in the medium (relaxed) range/only rare deviations	0
Restricted	Occasional positions or movements of the joints at the limit of the movement ranges	1
Unfavourable	Frequent positions or movements of the joints at the limit of the movement ranges	2
Poor	Constant positions or movements of the joints at the limit of the movement ranges/enduring static holding of the arms without hand-arm support	3

The result for the hand/arm positions and movements also needs to be weighed against the total duration and the total frequency of which the operator is exposed. Calculating the weighted result for the area concerning the hand/arm positions and movements are made with the following equation:

$$Wr_{hand/arm} = \frac{P_{hand/arm}}{60} * (t_{Exposed} + r_{Exposed})$$

where:

$Wr_{hand/arm}$	: Weighted result for the hand/arm positions
$P_{hand/arm}$	: Rated points for the hand/arm positions and movements
$t_{Exposed}$	: The time, in seconds, the operator is being exposed
$r_{Exposed}$	: The number of repetitions performed by the operator

The rated points are not visible in the ErgoRAV with the purpose to give a non-biased result. Typical postures for these areas are to be taken into account but rare deviations can be ignored [18].

Work Environment and Individual Adaptation
The question generated in this category was:

- Is the task performed inside the car or inside the engine compartment? [Yes/No]

The questions have the purpose to highlight whether there is adequate room or not to perform given working movements and to make sure that the task has physical freedom of movement. At the assembly plant, there is only one situation where the operator has limited physical freedom of movement and that is when working inside the car or engine department. If the answer to this question is yes, this area receives a rating point of one and if the answer is no, the rating point equals zero. The given rating point is then used in the final calculation in section 5.3.2.

Visual Conditions and Placement of Equipment
The questions generated in this category were:

- Can the operator see the work object without effort, i.e. without stressful postures? [Yes/No]
- If the answer is no: Is the task customized to be performed hidden? [Yes/No]

Visual conditions need to be taken into consideration in the ErgoRAV since it is clearly mentioned in the VCC ergonomic standard [26] that the accessibility and field of vision must not be restricted and that hidden assembly without a guide should not be used. These questions aim to capture this.

If both these questions receive the answer no then the final result of the ErgoRAV results in red.

Lifting Aids and Work Technique
The questions generated in this category were:

- Are the aids available at the station used? [Yes/No]
- If the answer is yes: Are they used in a proper way? [Yes/No]
- Is the task performed in an ergonomically correct way? [Yes/No]

Investigation if lifting aids are needed/used in a proper way needs to be captured by the ErgoRAV. The tool also needs to capture the work technique being used at the station to ensure that proper information and education is available for the operators.

Grips, Handles, and Controls of Hand Tools and Equipment
The question generated in this category was:

- What kind of force transfer/gripping conditions does the station compris?

This area is included in KIM-MHO. There are three answer alternatives to this question with different rating points [18], see Table 5.13:

Table 5.13: KIM-MHO force transfer/gripping conditions and rated points

Classification	Description	Rated points
Optimum force transfer/application	working objects are easy to grip (e.g. bar-shaped, gripping grooves)/good ergonomic gripping design (grips, buttons, tools)	0
Restricted force transfer/application	greater holding forces required/no shaped grips	2
Force transfer/application considerably hindered	working objects hardly possible to grip (slippery, soft, sharp edges)/no grips or only unsuitable ones	4

Also this part of KIM-MHO is weighted depending on the total amount of time seconds and number of times the operator is exposed:

$$Wr_{Force\,transfer/gripping\,conditions} = \frac{P_{Force\,transfer/gripping\,conditions}}{60} * (t_{Exposed} + r_{Exposed})$$

where:

$Wr_{Force\,transfer/gripping\,conditions}$	:	Weighted result for the force transfer/gripping conditions
$P_{Force\,transfer/gripping\,conditions}$	:	Rated points for the force transfer/gripping conditions
$t_{Exposed}$	:	The time, in seconds, the operator is being exposed
$r_{Exposed}$	:	The number of repetitions performed by the operator

The weighted result for the force transfer/gripping conditions is used in the final calculation in section 5.3.2.

Work Variation and Recovery
This area is also covered in KIM-MHO [18] with three different alternatives, see Table 5.14:

Table 5.14: KIM-MHO work organization and rated points

Classification	Description	Rated points
Frequent variation of load situation	due to other activities/a number of work operations/adequate opportunity for recuperation	0
Rare variation of load situation	due to other activities/few work operations/recuperation times adequate	1
No/hardly any variation of load situation	due to other activities/few single movements per operation/high working rate due to high line balancing and/or high piece-work output/uneven work sequence with concurrent high load peaks/too little or too short recuperation times	2

VCC have clear instructions that the operator should rotate between stations because variation is necessary for the ergonomic situation. Therefore this question is not asked in the ErgoRAV since the rating point is set to be zero.

5.3.2 Result of Individual Stations

When all data is entered correctly in the ErgoRAV twp separate results are generated. The first result is referred to as the station score and comprises the following areas:

- Work postures and working movements
- Work environment and individual adaptation
- Grips, handles, and, controls of hand tools and equipment

The results from these areas are used to generate a station score:

$$Station\ score = 4.5 * (Wr_{Posture} + P_{Force\,exertion} + P_{Time\,left} + Wr_{hand/arm} +$$

$$P_{Inside\,car} + Wr_{Force\,transfer/gripping\,conditions})$$

where:

$Wr_{Posture}$	: Weighted result for the postures
$P_{Force\,exertion}$	: Rated points for the force exertions
$P_{Time\,left}$	: Rated points for the time left
$Wr_{hand/arm}$	: Weighted result for the hand/arm positions
$P_{Inside\,car}$	: Rated points if task is performed inside the car or engine compartment
$Wr_{Force\,transfer/gripping\,conditions}$	: Weighted result for the force transfer/gripping conditions

The constant 4.5 is the predetermined time rating points. The total duration of the activity per shift is set to be eight hours which gives a time rating point of 4.5.

If the station score is < 25, the station is classed as "green" which indicates a low exposure situation. If the station score is 25 to < 50 it is classed as "yellow" which signals a highly increased exposure situation where a redesign of the workplace is recommended. The last class is "red" which requires a score $>$ or equal to 50, there is a high exposure situation and a redesign of the workplace is necessary [19].

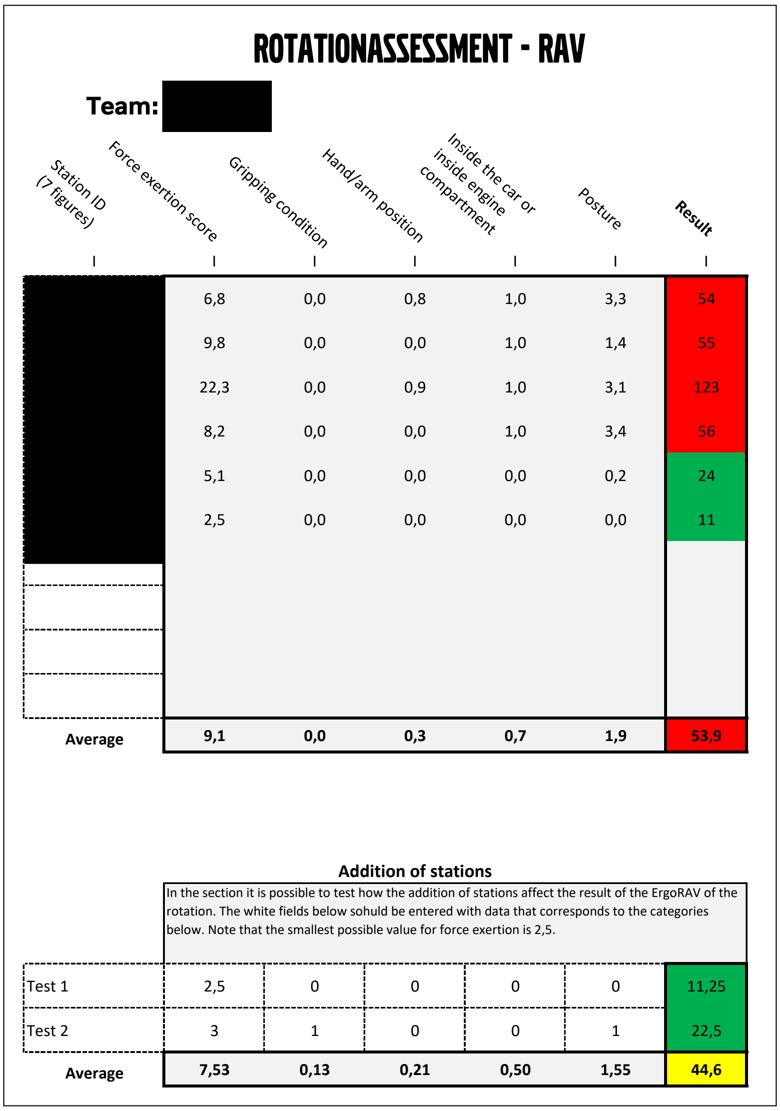
The second result comprises following areas:

- Visual conditions and placement of equipment
- Lifting aids

If the questions within these areas receive a "no" answer, the final result of the ErgoRAV is "red", no matter the station score from the first, calculated result.

5.3.3 Assessment of Rotations

Since VCC use work rotation as a tool to reduce the ergonomic loads, it was desired that a tool to assess the total ergonomic load on a rotation was created. The purpose of this tool was to enable a quick assessment of the ergonomic situation on a rotation since the operators rarely work on the same station a whole workday. The tool should also facilitate experimentation on how the addition or change of stations changes the ergonomic situation of the rotation. To make the rotation as user-friendly and convenient as possible, the tool for rotation assessment was created in Microsoft Excel with programmed functionality such as automatic loading of data from ErgoRAVs performed on the stations. The tool for assessment of rotation presents the ErgoRAV data from all included stations and then calculates the result for the rotation. The tool is presented in Figure 5.11. A complete description of how the rotation should be used can be found in Appendix A.4.



ROTATIONASSESSMENT - RAV

Team: [redacted]

Station ID (7 figures)	Force exertion score	Gripping condition	Hand/arm position	Inside the car or inside engine compartment	Posture	Result
[redacted]	6,8	0,0	0,8	1,0	3,3	54
	9,8	0,0	0,0	1,0	1,4	55
	22,3	0,0	0,9	1,0	3,1	123
	8,2	0,0	0,0	1,0	3,4	56
	5,1	0,0	0,0	0,0	0,2	24
	2,5	0,0	0,0	0,0	0,0	11
Average	9,1	0,0	0,3	0,7	1,9	53,9

Addition of stations

In the section it is possible to test how the addition of stations affect the result of the ErgoRAV of the rotation. The white fields below sohuld be entered with data that corresponds to the categories below. Note that the smallest possible value for force exertion is 2,5.

Test 1	2,5	0	0	0	0	11,25
Test 2	3	1	0	0	1	22,5
Average	7,53	0,13	0,21	0,50	1,55	44,6

Figure 5.11: Example of rotation assessment. *Team number and station ID are censored for confidentiality reasons.

The calculation of the result of the rotation assessment ErgoRAV is based on the KIM-MHO E and similar to the calculations of the ErgoRAV on station level. In KIM-MHO E, the total result is calculated by calculating weighted averages of the parameters mentioned in 5.3.1. Then by using the same formula as for calculating the result in the KIM-MHO, a result is generated. The KIM-MHO E assume that the sum of the times for the tasks entered in the field is equal to the actual total time for the assessed sequence. This means that if the user chooses to not enter data for all tasks in the sequence, the result will always be lower than if the whole sequence is assessed. To make the assessment less time consuming the new ErgoRAV will automatically assume that the rest of the time is spent performing the task with the parameters that give the lowest total result. This means that the total time will always be the same for all stations, in our case, 60 seconds. Therefore it is not necessary to weight the parameters against the time since the time is the same on all stations. In the KIM-MHO E the formula for the average of a weighed parameter is:

$$Weighted\,Parameter\,Average = \sum_{i=1}^{n} P_i * \frac{t_i}{\sum_{i=1}^{n} t_i}$$

where:

n : number of tasks
P_i : a parameter of task i
t_i : time of task i

In the rotation assessment ErgoRAV the formula for a parameter is:

$$Parameter\,Average = \frac{1}{n} * \sum_{i=1}^{n} P_i$$

where:

n : number of stations
P_i : a parameter of station i

5.4 Verification of Concept

In this section, the verification process of the new ErgoRAV will be presented. The tests were performed on different rotations in the assembly plant and the results from these will be presented. The issues found when performing the tests and the improvements that were implemented will be presented. The rotations that were chosen to be assessed were selected randomly without the thesis authors having knowledge of the current ErgoRAV results.

5.4.1 Field Test 1

The first test was performed by the thesis authors. It was performed together since the goal of the test was to identify the fundamental issues of the tool. The purpose of this test was also to find categories that need clarifications on how they should be assessed. The test was conducted at Doorline Vä, which is a line with, currently, a low number of red ErgoRAVs.

Results:
The test was aborted early since there existed fundamental issues in the tool that required immediate attention. Therefore, the first test did not generate any data on how the new ErgoRAV performs compared to the old one.

Issues found:
For the first test, only the force exertion score was weighted against the time of the performed task. It was realized that a bad work posture also needed to be weighted against time since a bad posture for 1 second, had the same consequences for the results as a bad posture for 60 seconds. This test was ended almost immediately to introduce the changes before continuing with the assessments.

Implemented improvements:
To avoid that the work posture affects the result too much, a system for weighting the parameters against the time spent performing the task was introduced. This weighted score is calculated by multiplying the posture score with the time of the task divided by the cycle time. The formula for the RAV-score was changed from:

$$Rotation\ Score = 4.5 * (f * \frac{t}{60} + p + h + g + wc)$$

to:

$$Rotation\ Score = 4.5 * (f * \frac{t}{60} + p * \frac{t}{60} + h + g + wc)$$

where:

p : Rated points for the postures
h : Rated points for the hand/arm positions
f : Rated points for the force exertions
g : Rated points for the time left
wc : Rated points if task is performed inside the car or engine compartment
t : time of the task

The result was that not as many stations as previously will be assessed as red since the overall score will always be lower than with the previous formula.

5.4.2 Field Test 2

Test 2 was conducted on a rotation at *Department D3* by the same team as in test 1. This time the goal was to perform an assessment of a whole rotation to compare the results with the old ErgoRAV and further identify issues with usability.

Results:
All stations on the rotation were assessed in test 2. According to the old ErgoRAV, one of the stations were assessed as red, and the rest as green. The test of the

new ErgoRAV result in three green station and three yellow stations. Two of the yellow station achieved a score below 30 and the other one achieved a score of 48. The complete result for test 2 is presented and compared to the result given by the currently used ErgoRAV in 5.15 below.

Table 5.15: Results from test 2

Description	Old result		Test result	
Station 1			19,4	
Station 2			27,7	
Station 3			19,6	
Station 4			15,6	
Station 5			28,1	
Station 6			47,9	
Final rotation score			26,5	

Issues found:
A flaw that was discovered was that the new ErgoRAV creates confusion if the assessed task only occurs for some car variants. It was unclear if the user needed to calculate the adjusted time/car manually or simply fill in the time the task is performed on the variant where it occurs. There was also some issues with how the descriptions of the force exertion levels and for the hand/arm positions where interpreted.

Another issue found was that checking the box for the chosen posture was often forgotten. This leads to unnecessary error messages and caused annoyance for the user.

Implemented improvements:
The unit for the boxes where the user fills in time and frequency was also changed from repetitions/car and duration/car to repetitions/cycle and duration/cycle respectively. This was to address the problem where confusion arose when some tasks only were performed at some product variants. Lastly, the check boxes for the postures were removed since filling in repetitions and duration is sufficient for indicating that the posture is chosen. The description of the force exertion levels and for the hand/arm positions where rewritten and clarified.

5.4.3 Field Test 3

Test 3 was performed on a rotation at *Department A4* which is a department with a high share of red ErgoRAVs. The rotation consists of 6 stations. Four of them are assessed as red, and two are assessed as green with the old ErgoRAV. The test was performed together by the team.

Results:
The assessments with the new ErgoRAV indicates that four of the stations are red and two are green. The results are presented and compared to the result given by the currently used ErgoRAV in Table 5.16.

Table 5.16: Result from test 3

Description	Old result		Test result	
Station 1			53,6	
Station 2			55,1	
Station 3			123,1	
Station 4			56,5	
Station 5			23,9	
Station 6			11,4	
Final rotation score			53,9	

Issues found:
Some of the work postures on line *Department A4* did not match up with the predefined postures in the new ErgoRAV. In some cases you have to choose whether to choose the posture according to the lower body or the upper body position. The question about hidden operations was also perceived as unclear.

Implemented improvements:
No improvements were implemented prior to test 4.

5.4.4 Field Test 4

The fourth test was conducted on a rotation at *Department D2* by the same team as in the previous tests. Here the tests were performed individually with the purpose to then compare the results and discuss the differences if any.

Results:
The results conducted by the team members compared to the result given by the currently used ErgoRAV is shown in Table 5.17.

Table 5.17: Individual results from the team members

Description	Team member 1		Team member 2		Old result	
Station 1	28,4		31,2			
Station 2	24,2		29,0			
Station 3	53,3		38,6			
Station 4	23,6		28,6			
Station 5	27,3		33,8			
Final rotation score	32,4		31,9			

As the table shows, the results vary on station level but the final rotation scores have marginal differences.

Issues found:
The question in the ErgoRAV concerning the hand/arm positions requires further explanation in the form of better visualizations which clarifies the areas of concern. It was misinterpreted on what areas this category included. The areas which need to be taken into account are the load on the finger, hand, elbow, and shoulder joints.

Notifications were also made that the questions within the category "Lifting aids" can be interpreted as the same thing and therefore need to be clarified further.

A big issue concerning the calculation of the final rotation score was discovered. The weighted results from the assessment of the individual station were also weighted in the assessment of the rotation. This resulted in an incorrect rotation score.

Implemented improvements:
Visualizations for the hand/arm positions were made to clarify that the areas taken into consideration are the load on the finger, hand, elbow, and shoulder joints.

The questions within the category "lifting aids" were discussed with the stakeholders and changed thereafter.

The weighting of the results from the individual station assessment was removed in the rotating score calculation.

5.5 Finalizing the ErgoRAV

Meetings were held with some of the stakeholders where the concept and the tests were explained and discussed. The concept was perceived to be adapted for usage only in car assembly plants, therefore, changes needed to be made to adapt the

ErgoRAV for global usage. One change that had to be made was to change the object in the pictures presenting the postures, to a box instead of a car. Another change concerned the formulation of the question within the "work environment and individual adaptation" category which only indicated work inside the car or engine department. To make it more globally applicable, the wording was changed to also included the description "cramped space".

There was a big discussion concerning the category "lifting aids" including the following questions:

- Are the aids available at the station used? [Yes/No]
- If the answer is yes: Are they used in a proper way? [Yes/No]
- Is the task performed in an ergonomically correct way? [Yes/No]

Regarding the first two points, the discussion was mainly about the importance of the fact that it was the station that was being assessed, not the operator. The ErgoRAV should capture whether the station is designed in a way that forces the operator to work incorrectly. With this question, the station might get a wrongly red result depending on if the operator performed the task incorrectly (not according to standard). This problem should, of course, be highlighted and fixed but it was discussed that this area was not supposed to be captured with the ErgoRAV. The station should not be assessed with the ErgoRAV if the operator does not work according to the standard.

The question on asking if the task is performed in an "ergonomically correct way" was interpreted as too difficult to answer and should be changed to "recommended", "standardized", or "agreed upon working technique". It was also discussed that this question maybe was not needed since it is required for the operator to work according to standard in order for the station to be assessed.

A description document that explains how the ErgoRAV should be used was requested. This description should include what criteria that need to be fulfilled before assessing, for example, that the operator needs to work according to the instructions. The description document also needs to include descriptions of how the user should interpret each question. The document can be seen in Appendix A.3.

After testing and discussion with stakeholders, the final questions generated were:

1. **Enter data for the postures that occur (maximum of 3), what force level applies and how many times/how long per cycle it is performed (0-60)** (see Figure 5.9)

2. **Is the task performed in a cramped space/inside the car/inside engine compartment?**
    - Yes/No

3. **What type of gripping condition does the task comprise?**
    - Alternative 1: Grip has a good ergonomic grip design, the object is easy and comfortable to grip
    - Alternative 2: Grip requires obstructed force transfer, more force is required to grip the object, the grip is improperly designed
    - Alternative 3: Grip is badly designed (slippery or sharp) or is missing, the object is nearly impossible to grip/grip is missing or is improper

4. **In what positions do hand/arm movements occur?** (see Figure 5.10)
    - Alternative 1: Good - Position or movements of joints in the medium (relaxed) range/only rare (see pictures in description document)
    - Alternative 2: Restricted - Occasional positions or movements of the joints at the limit of the movement ranges
    - Alternative 3: Unfavourable - Frequent positions or movements of the joints at the limit of the movement ranges
    - Alternative 4: Poor - Constant positions or movements of the joints at the limit of the movement ranges/enduring static holding of the arms without hand-arm support

5. **Can the operator see the work object without effort, i.e. without stressful postures?**
    - Yes/No

   a. If no, is the task designed to be performed hidden?
    - Yes/No
6. **Are the aids available at the work station used?**
    - Yes/No

   a. If yes, are they used in a correct way?
    - Yes/No

7. **Does the operator work according to recommended working technique?**
    - Yes/No

See the final design of the ErgoRAV in Appendix A.2.

6

Discussion

This work aims to contribute to creating a more sustainable work situation for the employees by identifying the risks of musculoskeletal disorders. The ambition is that the tool developed during this project will simplify the task of identifying hazardous ergonomic situations and resolving the issues as quickly as possible and before the injuries have already emerged. The tool will also increase safety for the employees as it decreases the risk of subjective and unfair assessments regarding the ergonomic situation.

6.1 Current State Analysis

The current state analysis contains conclusions from the quantitative and qualitative analysis. Below, these parts will be discussed.

6.1.1 Quantitative Analysis

The goal with the quantitative analysis was to identify if red ErgoRAVs correlate to reported musculoskeletal injuries. The goal was also to gather data that show interesting areas where the investigation could be continued with the qualitative analysis. The quantitative data analysis relied on data of injuries reported by operators and production leaders. The data set was limited to the year of 2018 which made the data set quite small but large enough to compare the data of the 5 PVC-areas. The production leaders at the 24 different departments are responsible for educating operators on reporting habits, and even finalizing the reports themselves. This makes the data affected by the routines of the production leaders. This makes it hard to draw conclusions on the station level or even department levels. It is known from this project that some departments have more injuries in the musculoskeletal area than is reported into the TIA database. The TIA database does not include information on what station, or at which team an injury occurred. This makes it even harder to draw conclusions on the connection between red ErgoRAVs and injuries.

6.1.2 Qualitative Analysis

The qualitative data collection had two primary goals: to investigate the reason for the results in the quantitative data analysis and to gain information on requirements and preferences for the new ErgoRAV. These two tasks where investigated during the same interviews to save time. To get a more fair representation of the opinions on the new ErgoRAV, more interviews with additional stakeholders could have been performed. It was chosen to not transcribe the interviews word by word to save time and resources. Instead, the interviews were summarized from notes that were written down during the interviews. The summaries were then sent to the interviewees to be approved. To not reveal the identities of the interviewees, it was decided not to publish the summaries in the report since some of them contain information that makes the identity obvious. Instead, a general, combined summary of the answers from the interviews was created to be published in the report. This solution is not optimal as the writers of the summary could affect the outcome of the interviews.

6.2 Improvement of the ErgoRAV

To increase the credibility of the results achieved during the development of the new ErgoRAV, several concepts could have been created and assessed. But to deliver as useful a tool as possible, it was decided that one concept was created and improved during this project. If multiple concepts were created, each of them would have ended up in a state where they do not have the intended functionality.

The new ErgoRAV could have been based on several ergonomic assessment methods. The KIM-series was chosen since it was recommended by the Swedish Work Environment Authority and this was a requirement for Volvo Cars, and strive to adhere to. The new ErgoRAV ended up being based on the KIM-MHO method, which is designed for assessing tasks that mainly includes exertion of hands, arms, and shoulders. During the early stages of this project, the new ErgoRAV was supposed to be based on KIM-LHC, which is used for lifting, holding, and carrying. The drawback with this method is that it is currently not possible to assess rotations with it. Instead, the possibility to base the new ErgoRAV on KIM-MHO was investigated. Even though it does not have the same focus area as KIM-LHC, the formula for calculating the result is similar. One difference is that KIM-MHO includes more areas such as work organization and hand/arm position. Another difference is that the category "force exertion" is not included in the KIM-LHC. Instead, there is a section where the weight of the lifted object is taken into account. KIM-MHO is suitable for the assembly line in Torslanda since most of the work is work with arms and hands, and does not involve heavy lifting. It is probably not the same story for other plants and areas, and the possibility of having different versions of the ErgoRAV for different areas should be investigated. These might even be based on different KIM-methods or even other ergonomic evaluation methods.

Having predetermined working postures to choose from can be both an advantage and a disadvantage. The new ErgoRAV was originally designed for use in the assembly plant at Volvo Cars Torslanda. The number of postures that occurs at the plant are limited and can be represented in a reasonable number of predetermined postures. Having predetermined postures is great for the usability of the tool but only if the postures represent the reality. When assessing a posture that is not closely represented by any of the postures in the new ErgoRAV, there will be confusion and the result might not be reliable. If the new ErgoRAV will be used globally, the predetermined postures need to represent all postures at all plants all over the world. This naturally increases the risk of not finding a matching posture and decreases the reliability of the tool. A solution to this would be to adapt the choice of predetermined postures for every plant according to the local conditions. Though, this would demand extra resources and might reduce the possibility to compare ergonomic conditions between plants.

The ErgoRAV applies a constant value in the category "work variation and recovery" with the argument that VCC standardize that the operators are to rotate during their shift. A discussion came up where this area was perceived differently from different stakeholders, some claimed that there was no frequent variation of the load situation and some claimed that it was. The ones claiming that there was a frequent variation of the load situation meant that the activities vary and are only performed a few times because of the rotation of stations. The rated points for this category is set to zero in the ErgoRAV, which indicates a frequent variation of the load situation. This can be further taken up to discussion and the rating point can be changed if required.

The takt time in the new ErgoRAV is predetermined to be 60 seconds and can currently not be changed by the user. If the takt time is to be changed, changes has to be made in the calculations, both in the station and rotation assessments since the value of the takt time is critical when weighting the results from the postures and the hand/arm positions.

Another important issue with the new ErgoRAV is that the rotation assessment tool does not take into account the order of the stations. In reality, it could mean that the operator might work on multiple red stations successively. This could have a negative impact on the operator since the possibility to rest during that period is substantially decreased.

6.3 Ethical Considerations

There have been several questions regarding ethical considerations throughout the project, mainly concerning confidentiality. Personal data has been processed and measures had to be made to assure the participant's privacy. When dealing with the TIA database which contains information regarding operators who has experienced musculoskeletal disorders, actions were taken to assure that only the information necessary for the project was visible. This meant that all personal details on the injured were hidden. The information which was processed was about the date of the reported injury and what area of the body that was injured.

When performing interviews it was communicated to all participants what the purpose of the study was, what their role was, and how the information they gave was going to be processed. The material used in the report from the interviews was sent to all participants for approval.

There exist requirements from Volvo Cars that there is information in the report which cannot be public. The ethical review requirements from Volvo Cars are that no sensitive data can be published meaning personal data and data that can be harmful to VCC if put into the wrong hands.

7
Conclusions

- **What effects does the current version of the ErgoRAV have?**
  Data collection of the current state of the ErgoRAV presented a correlation between reported injuries and red ErgoRAVs on an overall level.

- **How trustworthy is the ErgoRAV today?**
  The perception of the ErgoRAV appeared as trustworthy among almost all interviewed stakeholders but the questions were perceived as interpretable which led to conflicts between the different parties, mainly between VCT and the union, because of the diffuse results.

- **What does a station that has been evaluated as red in the ErgoRAV actually mean for the operators in terms of working conditions?**
  It is currently not possible to answer in detail what a station with a red ErgoRAV means for the operators in terms of working conditions due to lack of detail in the data of the reported injuries.

- **How can the new ErgoRAV be changed to increase the accuracy of the screening?**
  The new version of the ErgoRAV is developed to increase the accuracy of the screening compared to the old version and to make the screening tool more trustworthy and objective for the employees at VCT.

- **How can the ErgoRAV be used to analyze several stations (a rotation)?**
  A tool with the possibility to analyze several stations (a rotation) was created and will help in identifying strenuous rotations. The rotation tool also makes it possible to identify possible solutions by adding test stations.

8 Recommendations for Future Research

There are several suggestions for further improvements that can be made within the area of ergonomics at VCC which this section aims to present.

8.1 Digitization of the ErgoRAV

It is relatively new for VCC to present the ErgoRAV results on their intranet with the RAV attached as a Microsoft Excel file. The digitization process of the RAV could be taken even further. It would simplify the usage if the RAV was available for assessment online. The subjective factor needs to be small in order for the results to be in the same format which is necessary when combining the ErgoRAVs for assessing a rotation. It would also simplify when scrutinizing the RAVs, both for individual stations and for rotations, to have all data available on the same location, using links instead of needing to download several files.

8.2 Education Material

The qualitative data collection, stakeholder interviews, showed that it was eligible to improve the education material for the RAV. Information on how the RAV works and its purpose could be visible on the team boards at each rotation. New employees could benefit from a broader introduction concerning the RAV, and ergonomics in general.

Currently, the training on how to use the RAV, which needs to be completed in order to perform a RAV assessment, is done through lessons together with Health & Safety. If there was a possibility for the RAV training to be performed digitally, through electronic learning, this could result in time-saving for the Health & Safety department as well as increasing the availability for more workers to do the training. This method could also be used for new employees to inform on the importance of ergonomics in an environment such as an assembly plant.

8.3 Future Ergonomic Assessment Tools

Physical risks at the workplace are difficult to recognize and prevent if there is lack of expertise and resources to perform a well-informed risk assessment. There could also be a lack of time-efficient methods which does not require a long learning period.

One solution to this can be to record physiological signals and movement patterns through multiple sensors integrated into clothing. The long-term vision with research in this area is to develop an automated and comprehensive system of smart work clothing that will measure, assess and communicate. Also, to make it possible to visualize risks for musculoskeletal disorders based on physical workload, and through this provide a basis for the prevention of musculoskeletal disorders [33].

There are plenty of research in these areas, research with the purpose to find tools that will help indicate risks of musculoskeletal disorders, tools with the same goal as the ErgoRAV.

Bibliography

[1] International Ergonomics Association. (2019). *Definition and Domains of Ergonomics.* [online] Available at: https://iea.cc/whats/index.html?fbclid=IwAR3gGF-cth9APVMzvwLfvrRCQR3hJJ8kNqqo6an-9QeLETrchcoVM0g4xTg [Accessed 26 Jun. 2019].

[2] G. David, "Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders", *Occupational Medicine*, vol. 55, no. 3, pp. 190-199, 2005. Available: 10.1093/occmed/kqi082

[3] Z. Xu, J. Ko, D. Cochran and M. Jung, "Design of assembly lines with the concurrent consideration of productivity and upper extremity musculoskeletal disorders using linear models", *Computers & Industrial Engineering*, vol. 62, no. 2, pp. 431-441, 2012. Available: 10.1016/j.cie.2011.10.008

[4] E. Schneider and X. Irastorza, "Work-related musculoskeletal disorders in the EU". *Luxemburg: European Agency for Safety and Health at Work (EU-OSHA)*, 2010.

[5] S. Ferguson, W. Marras, W. Gary Allread, G. Knapik and R. Splittstoesser, "Musculoskeletal disorder risk during automotive assembly: current vs. seated", *Applied Ergonomics*, vol. 43, no. 4, pp. 671-678, 2012. Available: 10.1016/j.apergo.2011.10.001

[6] C. Berlin and C. Adams, "Production Ergonomics: Designing Work Systems to Support Optimal Human Performance", 2017. Available: 10.5334/bbe

[7] J. Oakman, W. Macdonald, T. Bartram, T. Keegel and N. Kinsman, "Workplace risk management practices to prevent musculoskeletal and mental health disorders: What are the gaps?", *Safety Science*, vol. 101, pp. 220-230, 2018. Available: 10.1016/j.ssci.2017.09.004

[8] S. Hignett and L. McAtamney, "Rapid Entire Body Assessment (REBA)", *Applied Ergonomics*, vol. 31, no. 2, pp. 201-205, 2000. Available: 10.1016/s0003-6870(99)00039-3.

[9] L. McAtamney and E. Nigel Corlett, "RULA: a survey method for the investigation of work-related upper limb disorders", *Applied Ergonomics*, vol. 24, no. 2, pp. 91-99, 1993. Available: 10.1016/0003-6870(93)90080-s.

[10] V. Louhevaara, T. Suurnäkki, S. Hinkkanen and P. Helminen, *OWAS: a method for evaluation of postrual load during work*. Helsinki: Institute of Occupational Health. Centre for Occupational Safety, 1992.

[11] T. Waters, V. Putz-Anderson and A. Garg, *Applications manual for the revised NIOSH lifting equation. Cincinnati*, Ohio: NIOSH, 1994.

[12] *Manual Handling Guidelines: Using Liberty Mutual Tables.* Boston: Liberty Mutual Insurance, 2017. Retreived from: https://libertymmhtables.libertymutual.com/CM_LMTablesWeb/taskSelection.do?action=initTaskSelection

[13] Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, "Heben und Tragen ohne Schaden". *The Federal Institute for Occupational Safety and Health*, Auflage, 2011. Retreived from: https://www.baua.de/DE/Angebote/Publikationen/Praxis/A7.pdf?__blob=publicationFile&v=2

[14] Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, "Ziehen und Schieben ohne Schaden". *The Federal Institute for Occupational Safety and Health*, Auflage, 2008. Retreived from: https://www.baua.de/DE/Angebote/Publikationen/Praxis/A25.pdf?__blob=publicationFile&v=2

[15] Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, "Key indicator method for assessing physical workload during manual handling operations". *The Federal Institute for Occupational Safety and Health*, Version 2012, 2012.

[16] Arbetsmiljöverket, "Bedöm risker vid manuell hantering - lyfta och bära, KIM 1". 2018, Retrieved from: https://www.av.se/arbetsmiljoarbete-och-inspektioner/publikationer/broschyrer/bedom-risker-vid-manuell-hantering---lyftabara-adi627-broschyr/

[17] Arbetsmiljöverket, "Bedöm risker vid manuell hantering – skjuta/dra, KIM 2". 2012, Retrieved from: https://www.av.se/globalassets/filer/publikationer/broschyrer/bedom-risker-vid-manuell-hantering-skjuta-dra-broschyr-adi668.pdf

[18] Arbetsmiljöverket, "Bedöm risk för belastningsskada - repetitivt arbete, KIM 3". 2012, Retrieved from: https://www.av.se/globalassets/filer/checklistor/riskbedomning-repetitivt-arbete-kim-3-checklista.pdf

[19] A. Klussmann, F. Liebers, H. Gebhardt, M. Rieger, U. Latza and U. Steinberg, "Risk assessment of manual handling operations at work with the key indicator method (KIM-MHO) — determination of criterion validity regarding the prevalence of musculoskeletal symptoms and clinical conditions within a cross-sectional study", *BMC Musculoskeletal Disorders*, vol. 18, no. 1, 2017. Available: 10.1186/s12891-017-1542-0

[20] U. Steinberg, F. Liebers, A. Klußmann, Hj. Gebhardt, M. A. Rieger, S. Behrendt, U. Latza, "Leitmerkmalmethode Manuelle Arbeitsprozesse 2011". *BAuA*, 2011. Retreived from: https://www.baua.de/DE/Angebote/Publikationen/Berichte/F2195.pdf?__blob=publicationFile&v=6

[21] A. De Groot and A. Groot, "Methodology. Foundations of inference and research in the behavioral sciences". *The Hague: Mouton*, 1969.

[22] A. Steckler, K. McLeroy, R. Goodman, S. Bird and L. McCormick, "Toward Integrating Qualitative and Quantitative Methods: An Introduction", *Health Education Quarterly*, vol. 19, no. 1, pp. 1-8, 1992. Available: 10.1177/109019819201900101.

[23] A. Graziano, Research Methods: Pearson New International Edition: A Process of Inquiry. *Harlow: Pearson*, 2013, p. 135.

[24] J. Miles and P. Gilbert, "A handbook of research methods in clinical and health psychology". *Oxford: Oxford University Press*, 2005. pp.65-67.

[25] M. Taylor, C. McNicholas, C. Nicolay, A. Darzi, D. Bell and J. Reed, "Systematic review of the application of the plan–do–study–act method to improve quality in healthcare", *BMJ Quality & Safety*, vol. 23, no. 4, pp. 290-298, 2013. Available: 10.1136/bmjqs-2013-001862

[26] Volvo Car Corporation, "Ergonomic requirements - Application (Standard No. VCS 8003,29)", 2014. [Standard only for internal use, confidential]

[27] AFS 2012:2 Provisions and General Recommendations of the Swedish Work Environment Authority on Ergonomics for the Prevention of Musculoskeletal Disorders.

[28] Directive (EU) 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).

[29] Directive (EU) 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum safety and health requirements regarding the exposure of workers to the risks arising from physical agents (noise)

[30] Directive (EU) 89/391/EEC of the European Parliament and of the Council of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work

[31] Directive (EU) 90/269/EEC of the European Parliament and of the Council of 29 May 1990 on the minimum health and safety requirements for the manual handling of loads

[32] Bundensanstalt für Arbeitsschutz und Arbeitsmedizin, "Bestimmung der Wichtung der Art der Kraftausübung - LMM MA E 2011-2", 2011. [unpublished document received from Bundensanstalt für Arbeitsschutz und Arbeitsmedizin]

[33] L. Yang et al., "Towards Smart Work Clothing for Automatic Risk Assessment of Physical Workload", *IEEE Access*, vol. 6, pp. 40059-40072, 2018. Available: 10.1109/access.2018.2855719

A

Appendix 1

A.1 The New RAV Cover Sheet

RISK ANALYSIS VOLVO - RAV

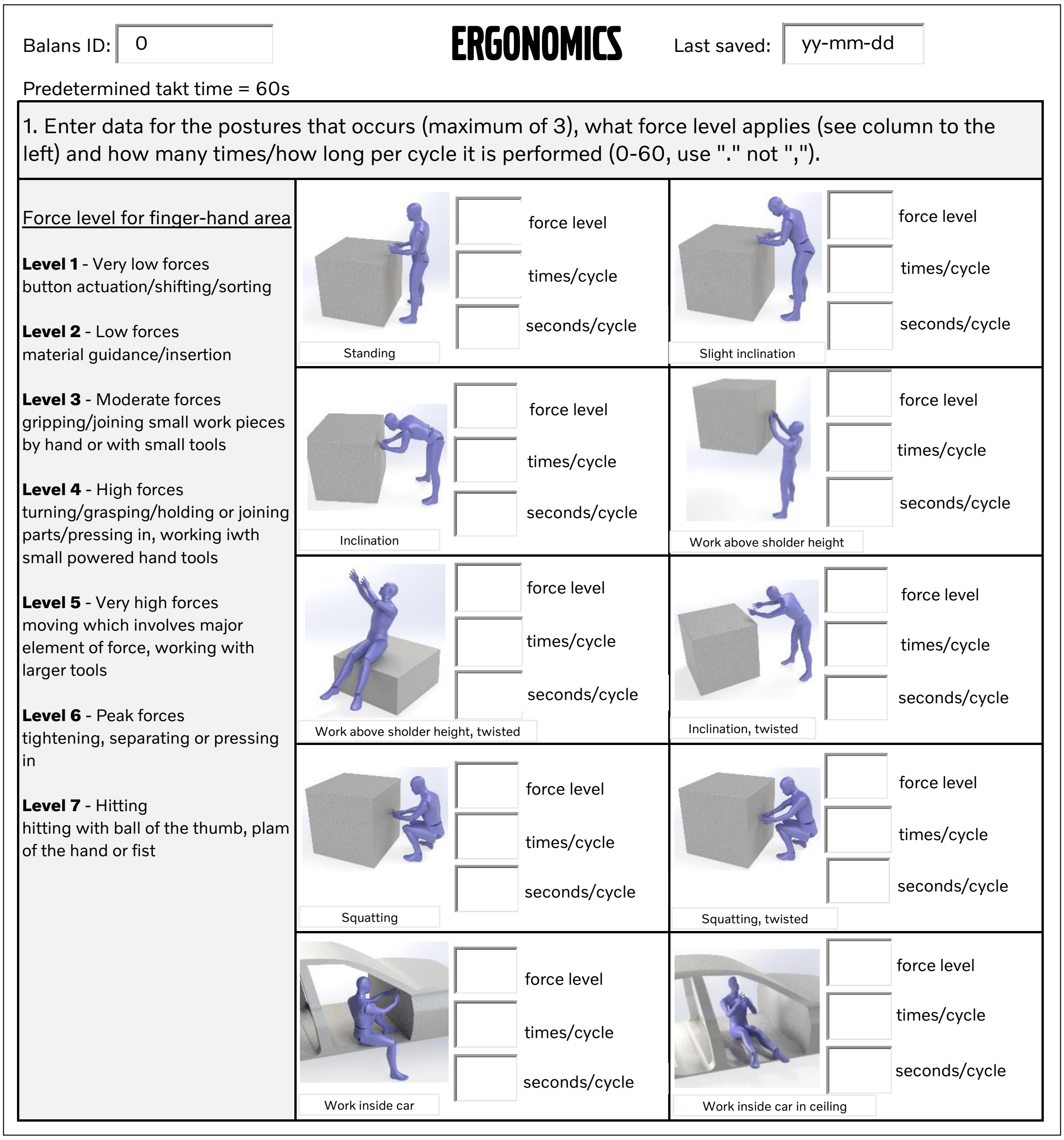
Executer (Dept, Name, cds-id):	Phone nr:	Date:	Edition:
Area and stations number:			Info class:
RAV- team participants (name):			

Risk area	Station/Rout	Operator		Risks and actions
Noise	Green	Red		
Lightning	Green	Red		
Accident risk	Green	Red		
Machine safety	Green	Green		
Chemical use	Green	Green		
Electrical safety hybrid vechicles	Green	Red		
		from an ergonomics	Rotation assessment	
Ergonomics	Green	Green	Red	
Industrial vehicles	Green			

Personal Protection Equipment

Safety gloves

A.2 The New ErgoRAV



Balans ID: 0

ERGONOMICS

Last saved: yy-mm-dd

Predetermined takt time = 60s

1. Enter data for the postures that occurs (maximum of 3), what force level applies (see column to the left) and how many times/how long per cycle it is performed (0-60, use "." not ",").

Force level for finger-hand area

Level 1 - Very low forces
button actuation/shifting/sorting

Level 2 - Low forces
material guidance/insertion

Level 3 - Moderate forces
gripping/joining small work pieces by hand or with small tools

Level 4 - High forces
turning/grasping/holding or joining parts/pressing in, working iwth small powered hand tools

Level 5 - Very high forces
moving which involves major element of force, working with larger tools

Level 6 - Peak forces
tightening, separating or pressing in

Level 7 - Hitting
hitting with ball of the thumb, plam of the hand or fist

Posture			
Standing	force level	times/cycle	seconds/cycle
Slight inclination	force level	times/cycle	seconds/cycle
Inclination	force level	times/cycle	seconds/cycle
Work above sholder height	force level	times/cycle	seconds/cycle
Work above sholder height, twisted	force level	times/cycle	seconds/cycle
Inclination, twisted	force level	times/cycle	seconds/cycle
Squatting	force level	times/cycle	seconds/cycle
Squatting, twisted	force level	times/cycle	seconds/cycle
Work inside car	force level	times/cycle	seconds/cycle
Work inside car in ceiling	force level	times/cycle	seconds/cycle

2. Is the task performed in a cramped space/inside the car or in the engine compartment?
☐ Yes ☐ No

3. What type of gripping condition does the task comprise?		
☐ Grip has a good ergonomic grip design, the object is easy and comfortable to grip	☐ Grip requires obstructed force transfer, more force is required to grip the object, the grip is improperly	☐ Grip is badly designed (slippery of sharp) or is missing, the object is nearly impossible to grip/grip is

4. In what position does hand/arm movements occur? (see explaining pictures in the description document)			
☐ Good: Position or movements of joints in the medium (relaxed) range/only rare	☐ Restricted: Occasional positions or movements of the joints at the limit of the movement ranges	☐ Unfavourable: Frequent positions or movements of the joints at the limit of the movement ranges	☐ Poor: Constant positions or movements of the joints at the limit of the movement ranges/enduring static

5. Can the operator see the work object without effort, i.e. without stressful postures? *The work object cannot, according to VCC Ergonomic standard, be hidden.*	☐ Yes ☐ No
If no, is the task designed to be performed hidden? *If assembly is performed hidden there must exist guiding for the work object.*	☐ Yes ☐ No
Comment:	*Recommended action:*

6. Are the aids available at the work station used? *It is important that proper training has been executed on how and why aids are to be used.*	☐ Yes ☐ No
If yes, are they used in a correct way?	☐ Yes ☐ No
Comment:	*Recommended action:*

7. Does the operator work according to recommended working technique? *It is important that there exist work instructions and that education has been completed which guides the operator to work in an ergonomically correct way.*	☐ Yes ☐ No
Comment:	*Recommended action:*

Generate result | Clear document

End result	
Result for part 1 (question 1-4)	**0,0**

Green < 25
Low load situation,
health risk from physical overload is unlikely to appear.

Yellow 25 < 50
Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.

Red >= 50
High load situation, physical overload is likely to appear.
Workplace redesign is necessary.

A.3 Description of the ErgoRAV

DESCRIPTION ERGORAV

When assessing with the ErgoRAV following is presumed:

- The operator work according to assigned work instructions
- The RAV-team is complete

(It is assumed that the points in today's detailed instruction of the RAV is followed)

To be considered:

- The ErgoRAV is currently designed for use in the TC factory.
- If the tool is to be used in other factories then a reconstruction of the visualization of the postures needs to be made.
- In order for the tool to generate as good result as possible the visualization of the postures should be taken from the factory in which the tool will be used in.
- Important to highlight is that the ErgoRAV is in a concept phase, it is not a finalized tool, and therefore needs to be used with caution.
- Always save the document as a "Microsoft Excel Macro-Enabled Worksheet"

The user starts by entering the stat-ID.
The date is automatically generated when the user presses the button “Generate result”

Question 1-4

The first part (question 1-4) contains point based questions where formulas are used to calculate a result which decides the colour of the station

1. Enter data for the postures that occurs (maximum of 3), what force level applies (see column to the left) and how many times/how long per cycle it is performed (0-60, use "." not ",").

- The station that is being assessed shall be observed at least 5 cycles
- The points are generated based on the entered values for the force level and how long/how many times the operator works in that posture
- Choose the postures that matches the operators position the best, if the posture is not visualised then choose the posture most similar (to the worst)
- The type of force exertion(s) (force level) to be evaluated is in the finger-hand area
- The user can choose between 1-3 postures
- The formula which is used to calculate the points is the following:

$$P_{Force\,exertion} = \sum_{n=1}^{3} 2,5 * f * \frac{t_{Exposed}}{60} + \sum_{n=1}^{3} 2,5 * f * \frac{r_{Exposed}}{60}$$

where:

$P_{Force\,exertion}$	: Rated points for the force exertions
n	: Number of selected postures
f	: Force constant
$t_{Exposed}$	: The time, in seconds, the operator is being exposed
$r_{Exposed}$	: The number of repetitions performed by the operator

2. Is the task performed in a cramped space/inside the car/inside engine compartment? [Yes/No]

- Yes: The space of movement is limited — points = 1
- No: Plenty of space, no physical obstacles in the work area — points = 0
- The user is to choose one of the alternatives

3. What type of gripping condition does the task comprise? [Points 0-4]
The user is to choose one of the alternatives

Grip has a good ergonomic grip design: points = 0

- The object is easy and comfortable to grip

Grip requires obstructed force transfer: points = 2

- More force is required to grip the object, the grip is improperly designed

Grip is badly designed (slippery of sharp) or is missing: points = 4

- The object is nearly impossible to grip/grip is missing or is improper

4. In what position does hand/arm movements occur? **[Points 0-3]**
The user is to choose one of the alternatives

Good: points = 0

- Position or movements of joints in the medium (relaxed) range/only rare

Restricted: points = 1

- Occasional positions or movements of the joints at the limit of the movement ranges

Unfavourable: points = 2

- Frequent positions or movements of the joints at the limit of the movement ranges

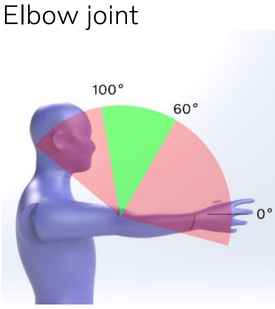
Poor: points = 3

- Constant positions or movements of the joints at the limit of the movement ranges/enduring static holding of the arms without hand-arm support

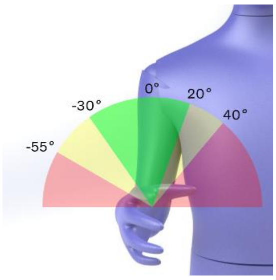
Where a large number of joints are involved, a general overall estimation must be made.

Following pictures clarifies what areas that indicates good/restricted/unfavourable/poor postures and movements:

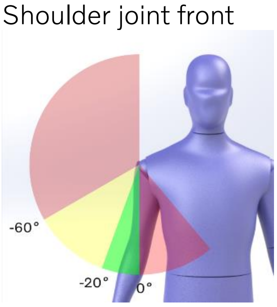
Elbow joint



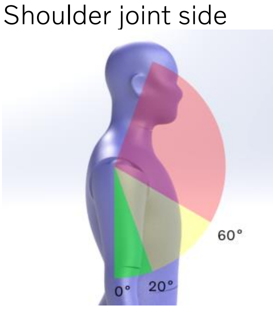
Lower arm



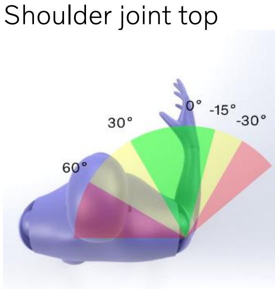
Shoulder joint front



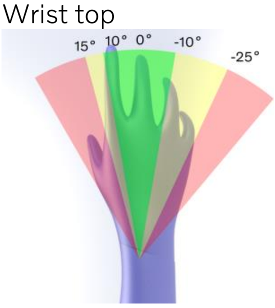
Shoulder joint side



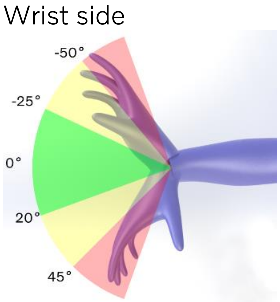
Shoulder joint top



Wrist top



Wrist side



All generated points are weighted depending on their frequency/duration for the operator and the collected points from question 1-4 is received from the following formula where 4,5 is equal to a time constant:

$$Station\ score = 4.5 * (Wr_{Posture} + P_{Force\ exertion} + P_{Time\ left} + Wr_{hand/arm} + P_{Inside\ car} + Wr_{Force\ transfer/gripping\ conditions})$$

where:

$Wr_{Posture}$	:	Weighted result for the postures
$P_{Force\ exertion}$	:	Rated points for the force exertions
$P_{Time\ left}$	:	Rated points for the time left
$Wr_{hand/arm}$	:	Weighted result for the hand/arm positions
$P_{Inside\ car}$	:	Rated points if task is performed inside the car or engine compartment
$Wr_{Force\ transfer/gripping\ conditions}$	:	Weighted result for the force transfer/gripping conditions

The limits and recommendations for the result from question 1-4 is the following:

Green < 25
Low load situation, health risk from physical overload is unlikely to appear.

Yellow 25 < 50
Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.

Red >= 50
High load situation, physical overload is likely to appear.
Workplace redesign is necessary.

Question 5-7 is yes/no questions where a no answer makes the ErgoRAV receive a red result

5. Can the operator see the work object without effort, i.e. without stressful postures? [Yes/No]
   a. If no, is the task designed to be performed hidden? [Yes/No]

   If answer on question 5 is no then question 5a needs to be answered.

Answer to question 5:	Answer to question 5a:	Result
No	No	Red ErgoRAV result
No	Yes	Green ErgoRAV result
Yes	-	Green ErgoRAV result

The work object cannot, according to VCC Ergonomic standard, be hidden. If assembly is performed hidden there must exist guiding for the work object.

6. Are the aids available at the work station used? [Yes/No]
   a. If yes, are they used in a correct way? [Yes/No]

If answer on question 6 is yes then question 6a needs to be answered.

Answer to question 6:	Answer to question 6a:	Result
No	-	Red ErgoRAV result
Yes	No	Red ErgoRAV result
Yes	Yes	Green ErgoRAV result

It is important that proper training has been executed on how and why aids should be used

7. Does the operator work according to recommended working technique? [Yes/No]
   Yes: Green ErgoRAV result
   No: Red ErgoRAV result

The user is to choose one of the alternatives

It is important that there exist work instructions and that education has been completed which guides the operator to work in an ergonomically correct way.

The user presses the button “Generate result” and the score from question 1-4 is calculated and the final result is decided where all questions, 1-7 is taken into consideration.

The result from question 5-7 weights heavier than the score from question 1-4.

If the user want to clear the document the button ”Clear document” is used, observe that the previous result then will be cleared.

A.4 Description of the Rotation Assessment

DESCRIPTION ERGORAV,
ASSESSMENT OF ROTATION

When assessing with the ErgoRAV following is presumed:

- The operator work according to assigned work instructions
- The RAV-team is complete

(It is assumed that the points in today's detailed instruction of the RAV is followed)

To be considered:

- Important to highlight is that the ErgoRAV is in a concept phase, it is not a finalized tool, and therefore needs to be used with caution.
- The result of the tool is not affected by order of the stations. However, to get a visual overview the stations should be entered in the order that they are performed.
- The rotation assessment intends to only assess complete rotations where the total time of work is one shift (8 hours)
- Always save the document as a "Microsoft Excel Macro-Enabled Worksheet"


ROTATIONASSESSMENT - RAV
Team: [redacted]
1
Station ID (7 figures)
Force exertion score
Gripping condition
Hand/arm position
Inside the car or inside engine compartment
Posture
Result
2
[redacted]
6,8 0,0 0,8 1,0 3,3 54
9,8 0,0 0,0 1,0 1,4 55
22,3 0,0 0,9 1,0 3,1 123
8,2 0,0 0,0 1,0 3,4 56
5,1 0,0 0,0 0,0 0,2 24
2,5 0,0 0,0 0,0 0,0 11
5
Average
9,1
0,
3
0,3
0
4
1,9
53,9
Load RAVs
Calculate Result
Reset Document
Addition of stations
In the section it is possible to test how the addition of stations affect the result of the ErgoRAV of the rotation. The white fields below sohuld be entered
data that corresponds to the categories below. Note that the smallest possible value for force ex
is 2,5.
6
7
2,5 0 0 0 0 11,25
3 1 0 0 1 22,5
9
Average
7,53
0,13
0,21
0,5
8
1,55
44,6
Calculate result with added stations

Name	Date modified	Type	Size
[redacted]	2019-04-10 10:04	Microsoft Excel Macr...	394 KB
	2019-04-10 09:44	Microsoft Excel Macr...	394 KB
	2019-04-10 10:02	Microsoft Excel Macr...	394 KB
	2019-04-10 10:10	Microsoft Excel Macr...	393 KB
	2019-04-10 11:03	Microsoft Excel Macr...	391 KB
	2019-04-10 10:20	Microsoft Excel Macr...	391 KB
	2019-04-10 11:07	Microsoft Excel Macr...	58 KB

1. How should the rotation assessment tool be used?

The rotation assessment tool is designed to give an overview of the ergonomic situation of a rotation. This is to be able to see how an operator's working day is affected by rotating between different stations. The data for the rotation is automatically retrieved from previously assessed ErgoRAVs. This only works if all ErgoRAVs on a rotation are named by station ID and are put in the same folder (see picture above). The name of the document for rotation assessment does not affect the function but is appropriately named similarly to the example above. White fields with dashed lines are filled by users and the rest are calculated automatically.

1. **Enter the team number where the assessment is performed (1).** This does not affect the functionality of the tool.

2. **Enter station IDs for the stations that are included in the rotation (2).** Those must be exactly the same as the file name for the RAVs that exists in the same folder as the file for the rotation assessment.

3. **Click the button "Load RAVs" (3).** Then data from the RAVs are loaded in and fills data for the categories that affects the result of the ErgoRAV. The results of the individual ErgoRAV are also presented in the rightmost column.

4. **Click the button "Calculate Result" (4).** An average of all the included factors are calculated for the RAVs and presented in the row at the bottom named "Average ". At the far right of this row (5) the result of the rotation is presented. This value is a measure of how all stations interact from an ergonomic perspective. The scale is the same as for the ErgoRAVs on a single balance level where a value between 11 and 25 is green, 25-50 yellow and where a value above 50 gives a red result. The button "Calculate results" exist to be able to change the values of the factors and then calculate the results again in order to see how the result is affected (if a change of station needs to be tested). The result is calculated by summing the average values for the factors and then multiplying by a time factor (always 4.5).

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change the values of the factors and then calculate the results again in order to see how the result is affected (if a change of station needs to be tested). The result is calculated by summing the average values for the factors and then multiplying by a time factor (always 4.5).

2. How to use the rotation assessment tool to test the addition of stations

Verktyget kan även användas för att testa hur addition av en balans kan påverka den ergonomiska situationen på en rotation. För att göra detta så följs stegen nedan. Notera att i denna version är det möjligt att testa att lägga till antingen 1 eller 2 balanser.

The tool can also be used to test how addition of stations affects the ergonomic situation of a rotation. To do this, the steps below should be followed. In this version if the tool, either one or two stations can be added.

1. **Enter the names of the stations that are to be added to the left in the "Addition of Stations" part.** This does not affect the functionality of the tool.
2. **Enter the data for the included factors (7).** The categories for these are the same as above. The possible values are the same as for the ErgoRAV on station level. Se table below for ranges of the values.

Force exertion score (Question 1 from the ErgoRAV)	2,5 - 50
Gripping conditions (Question 3)	0 - 4
Hand/arm position (Question 4)	0 - 3
Inside the car or inside the engine compartment (Question 2)	0 - 1
Posture (Pictures Question 1)	0 - 5

3. **Click the button "Calculate results with added stations" (8).** Then a new result is calculated where the added test stations are included. This result is presented in the lower right corner of the tool (9).

Alternatively:

If a current existing station will be added to the rotation it is possible to copy the RAV assessment of that station into the earlier mentioned folder. The name of the station is then entered according to point 2 in part 1. Then follow the rest of part 1 to calculate the result again.