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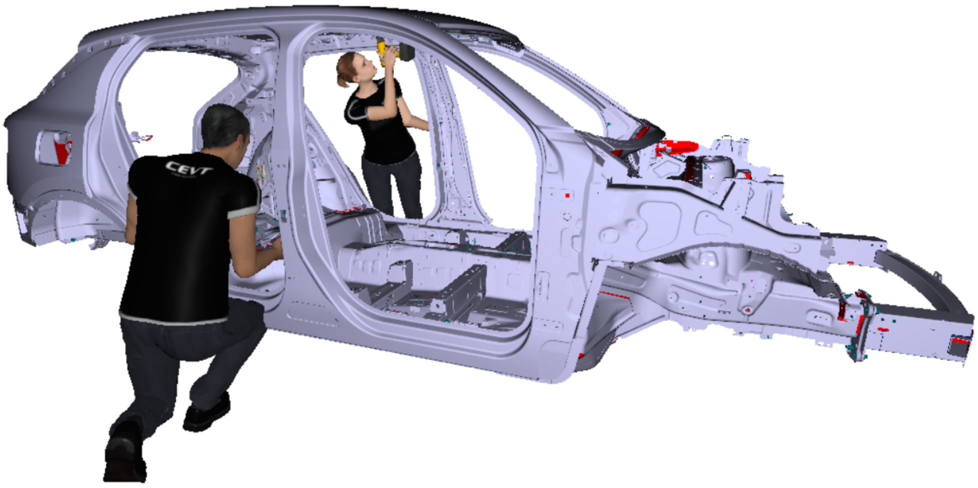

Simulations of ergonomic assembly

Ergonomic evaluation using the digital human modelling tool IMMA

Master's thesis in Production Engineering

LEONARD BOGOJEVIC
HENRIK SÖDERLUND

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

Master's thesis 2020:11

Ergonomic evaluation using a digital human modelling tool simulation

Implementation and validation of automated ergonomic assessments in the digital human modelling tool IMMA

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LEONARD BOGOJEVIC
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Supervisor: Anton Berce, CEVT
Liang Gong, Chalmers University of Technology
Examiner: Björn Johansson, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Two manikins of IMMA performing assembly operations of a car in the simulation software IPS.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2020

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Abstract

In regards to the vast amount of work-related injuries in today's industries, the way to assess and understand ergonomics as we know it, needs to change. Musculoskeletal disorder as a result of bad workplace design and ergonomics is one of the leading causes of work-related injuries. This is especially true for the manufacturing sector and the automotive industry. CEVT, *China Euro Vehicle Technology*, among other stakeholders in the industry, is taking initiative to reduce the risk of musculoskeletal disorders and is looking towards simulations and digital tools as a possible solution.

On behalf of CEVT, this thesis elucidates the implementation and validation of an automated ergonomic assessment within the digital human modeling software IMMA, *Intelligently Moving Manikins*. The ergonomic evaluation method KIM III, *Key Indicator Method*, was selected as the most appropriate method for implementation regarding CEVT's needs. The implementation led to an automated ergonomic assessment, providing a PDF report based on the manikins' posture and additional input data from the user. The implementation was validated against manual KIM III assessments conducted by a CEVT ergonomist and was proven successful.

The developed methodology of the thesis has been structured to fulfill the aims of the study and reach an implementation of a full evaluation assessment into the DHM, *Digital Human Modeling*, tool IPS, *Industrial Path Solutions*, IMMA. The focus has been to verify and obtain high validity of the implemented function, which could be achieved after undergoing a vast benchmarking and screening process. The benchmarking and screening process were the result of quantitative and qualitative data analyses and presented the most suitable ergonomic assessment method to be implemented in IPS. The method may be adapted to evaluate the relevance and suitability of ergonomic assessment methods into DHM software.

This thesis further addresses the need of future research within the field of virtual reality and motion capture as a way of better understanding the motion and behaviour of assembly workers. Furthermore, future development of digital twins as a way of better understanding the reality of the problem as well as the development of simulation based ergonomic assessment methods is discussed.

Keywords: Automotive, DHM, Ergonomic assessment methods, Ergonomics, IMMA, IPS, Musculoskeletal disorders, Simulations.

Acknowledgements

This thesis was carried out in collaboration with CEVT during the spring of 2020 in Gothenburg, Sweden, as a final project within the Master's program Production Engineering at Chalmers University of Technology. This report is the result of many hours of dedication, stubbornness, confusion and of course happiness. To work in close collaboration with the talented people at CEVT, at Chalmers, at Fraunhofer-Chalmers Centre and all other organisations that has been part of this project, has been a privilege - and for that we are truly grateful.

We would like to send massive thanks to the people who, during this project, have supported us or in any other way shown interest in our thesis. A special thanks goes out to our supervisor and examiner at Chalmers University of Technology, Liang Gong and Björn Johansson, for their dedication in not only our work with this thesis, but also for their dedication in our work during the entire Master's program. Their support and their tuition have been priceless to us.

We would also like to send a warm *thank you* to Anton Berce, our supervisor at CEVT. Your dedication and time spent in this thesis has created the prerequisites for a truly successful project and collaboration. It has been a true pleasure and an honour to work with you for the past couple of months, and your devotion has been sincerely appreciated.

We hope that our work on simulations of ergonomic assessments will help to avoid ergonomic risks in manual work at early stages. In times like these, with the current pandemic situation due to the COVID-19 virus, it has been clear to us that we need to look after and help each other. Our thoughts go out to the heroes of the society, the ones who are working daily to ensure that the people are safe and at health.

Thank you,

Leonard Bogojevic, Henrik Söderlund
Gothenburg, May 2020

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Nomenclature

	General Abbreviations
CEVT	China Euro Vehicle Technology
FCC	Fraunhofer-Chalmers Centre
ME	Manufacturing Engineering
MSD	Musculoskeletal disorder
MTM	Methods-time measurement

	Ergonomic assessments
EAWS	Ergonomic Assessment Worksheet
HARM	Hand Arm Risk Assessment Method
JSI	Job Strain Index
KIM	Key Indicator Method
OWAS	Ovako Working Posture Analysing System
RAMP	Risk management Assessment tool for Manual handling Proactively
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
SARA	Samlad Riskbedömningar Arbetsplatser [Collected risk assessment for workplaces]
VCS	Volvo Cars Standard

	Information Technology
API	Application Programming Interface
CSV	Comma-separated Values
DHM	Digital Human Modeling
GUI	Graphical User Interface
IMMA	Intelligently Moving Manikin
IPS	Industrial Path Solutions
JSON	JavaScript Object Notation
TCP	Tool Center Point
VBA	Visual Basic for Applications
VR	Virtual Reality

1
Introduction

This chapter presents the theoretical and practical background of the thesis by explaining the context of the study and its relevance. Problem identification, purpose, aim, scope and delimitation and a thesis outline are also presented in the current chapter to describe the focus of the thesis along with presenting the structure of the report.

1.1 Background

Every year, millions of people report taking time off from work to recover from their MSDs, *Musculoskeletal Disorder*, ultimately costing the society hundreds of billions of dollars annually [1][2]. MSD causes many humans to feel pain in their muscles and joints, which limits their ability to move and withstand loads for a longer period of time. These factors can be the direct consequence of bad ergonomics at a workplace, and could result in even more serious injuries if not treated properly [3]. A lot of the work-related MSDs are reported to originate from the automotive industry [4]. Moreover, bad ergonomics has shown to not only affect the musculoskeletal system, but also has big impact on production quality as well. On average, studies has shown that 80% of medium or high ergonomic loads in automotive productions results in quality problems [5][6].

The automotive market and its high-technology production systems have undergone rapid development in recent years towards a more efficient and more automated production system [7]. This trend has accelerated the development of new, innovative and smarter technology solutions which has improved the production and planning systems greatly [7]. In order to stay competitive on the market, automotive companies need to stand at the forefront of any new innovations and solutions as they aim to gain marketing shares by improving their production.

To ensure a sustainable production and obtain high quality of products while at the same time reduce lead times, automotive industries can gain great advantages by considering their production virtually before making real-world implementations [8]. By using such methods, companies can foresee challenges and prevent them from happening, even before they occur [8]. An example of such a challenge is manual assembly work which is strictly related to the ergonomics of the operators. In today's automotive industry, and most likely in the future, human assembly workers are considered as one of the most valuable resources. Therefore, making assembly operations ergonomically sound is crucial in order to ensure both human well-being and high product quality [9].

Today, most ergonomic assessments are carried out manually in an already existing production environment, using observational methods. This in turn could result in subjective evaluations and faulty measurements, as the data is interpreted by the person who is conducting the assessment [10]. The method takes a long time to complete and is also not as accurate as it could be. Therefore, in order to elevate the ergonomic validation process, one should consider the possibilities of implementing ergonomic evaluations in simulations and/or virtual reality systems. With the rise of simulations and DHM-software and its capabilities, the potential of analysing digital manikins in an automated way has increased. [11]. An example of such software is IPS and its DHM-function IMMA.

As simulations are carried out more and more frequently in the automotive industry in order to prepare and plan production, the use of DHM-software as IMMA has also increased drastically [11]. Digital manikins are used to verify reachability and accessibility of the workers at assembly stations [12]. Some companies have also started to add ergonomic evaluation tools to their DHM-simulations, with the aim of getting a more efficient and objective validation of the operators' work [12]. Consequently, workers at the ME/R&D department can make changes to improve the assembly workflow and thus prevent hazardous ergonomic assembly work from happening.

1.2 Aim and purpose

This master thesis maps how merging ergonomic assessment methods with virtual simulations can improve anthropocentric ergonomics, leverage performance and generate economic value in process development, product development and production technology at CEVT.

As part of the thesis project, a literature and interview study shall be held in order to analyse different ergonomic methods available as well as cross-linking them to the needs of CEVT. The result of the study shall later be merged into CEVT's existing DHM simulation tool IPS, with the aim of virtual reality compatibility. Cases of virtual simulations shall be defined to validate the results of the implemented ergonomic method as well as the capabilities of DHM simulation.

1.3 Scope and delimitations

The delimitations of the project are set in regards to data collection, project time and project resources. As the project will be conducted with CEVT, any other virtual simulation tools apart from IPS IMMA (version 3.8.2 and 3.9), their current DHM-simulation software, will not be considered in this thesis. Further limitations regarding the number of considered ergonomic standard methods will also be restricted by the relevance to the subject as well as the current time frame. The project is completed and limited to 20 weeks and with a group size of two.

For the sake of this thesis work the delimitation has been made to only address the physical loading part of ergonomics, thus excluding any cognitive aspect of the term such as psychological and social factors.

The implementation has been developed to primarily be used at the ME, *Manufacturing Engineering*, department for trim and final assembly as well as Body in White operations. Thus, any other cases that does not concern nor regard the ME department at CEVT, will be delimited, if not agreed otherwise.

1.4 Problem identification

The issue of concern regards to investigate further in the following statements:

- Identify the potential in merging ergonomic assessments in a digital human modeling tool.
- Perform a vast research study that implies and supports what ergonomic assessments methods are suitable to be implemented in the virtual simulation tool IPS IMMA.
- Define and implement ergonomic assessment method(s) into IPS IMMA.
- Gather qualitative input from the industry to validate and verify the methodology and the results.
- Perform an evaluation of how the developed ergonomic assessment method(s) could be used in the future.

By adopting the presented specification of issue, the aim is to find an elaborate answer to the following research question:

- How could ergonomic assessment of assembly work be automated using Intelligently Moving Manikins (IMMA) in a virtual simulation system?

1.5 Thesis outline

The following table presents an overview of the sections that are used in this document, see table 1.1. The thesis consists of seven sections, starting with the introduction, and are recommended to be read accordingly.

Table 1.1: Table of the thesis outline with a brief chapter description.

Chapter	**Title**	Description
Chapter 1	**Introduction**	*Introduces the issue of concern and relevant background information.*
Chapter 2	**Theory**	*Includes information and facts about the issue of interest that constitutes the fundamental knowledge of this thesis.*
Chapter 3	**Methodology**	*Explains how the project was structured and performed.*
Chapter 4	**Results**	*Consists of the most relevant results achieved from the performed methodology.*
Chapter 5	**Discussion**	*Highlights interesting discussion points regarding the methodology, results and the scope.*
Chapter 6	**Conclusion**	*Summarizes the most important achievements.*
Chapter 7	**Future work**	*Presents subjects that recommends to be followed up for future studies.*

2
Theory

In the following chapter, relevant theory regarding DHM, IMMA and ergonomics based on a literature and interview study will be presented with structured sections and subheadings.

2.1 Work-related MSDs

Work-related MSDs are one of the highest contributors to work-absences due to illness [12]. In 2017, MSD represented 23% of all cases of long-term sick leave in Sweden, resulting in huge cost for both employers and society [13]. The European Union estimates a total cost of total €240 billion a year, due to work-related MSDs [12]. Considering that work-related MSDs could be the result of bad ergonomics in the workplace, engineers and designers have the ability to prevent them from appearing as long as one is aware of the problem and its origin [12]. Examples of such origins and causes at faults could be; static working posture, too high load weight, repetitive work tasks, stress, lack of recovery time, bad working techniques etc. [12].

Statistics shows that around 45% of all work-related MSDs are the result of manual handling of material, involving lifting, carrying and assembling [14]. Meanwhile, another 22% is the result of awkward and static work posture [14].

2.2 Anthropometry and Physical loading

Anthropometry is the study of human measurements and is used in order to understand human physical variation. The physical variations among humans is evident as the variations in body measures varies from one person to the next with clear tendencies and patters visible between nationalities, gender and populations [12]. Hence, our bodies' ability to take up physical loads vary with the same deviation, as there is a strong correlation between the measurements of the human body, the measurements of the musculoskeletal system and the load it can endure [15]. In order to create products and workplaces suitable for everyone, anthropometric data needs to be consulted and a relevant percentage of the populace needs to be taken into consideration [15].

Anthropometry is calculated by measuring the length and thicknesses of the human body parts. Figure 2.1 illustrates some anthropometric measurements [16].

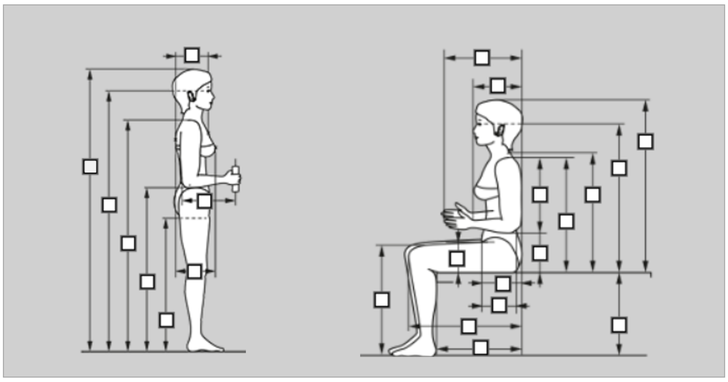


Figure 2.1: Figure presenting anthropometric data measurements, from IPS software.

Besides the measurements and anatomy of the human body, there is also a number of factors that interplay in its ability to take up load in a harmless way. Posture, force and time are the three most important factors to consider. The interaction between these factors will determine the risk and severity of potential injuries (e.g. MSD) connected to a specific physical load situation [12]. The relationship of these factors can in a simplified way be described by the cube model [17], see figure 2.2.

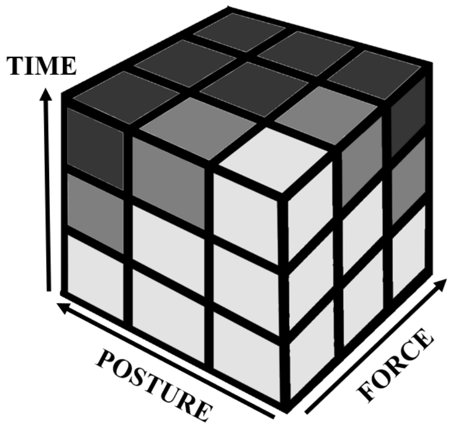


Figure 2.2: Illustration of the relationship between time, posture and force factors presented in a cube model based on Sperling et al. (1993) modified by Henrik Söderlund.

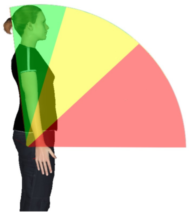
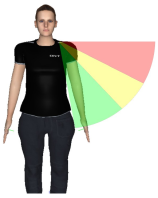
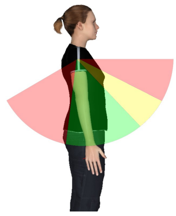
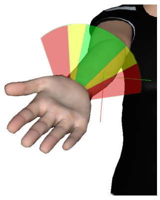
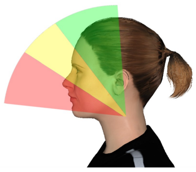
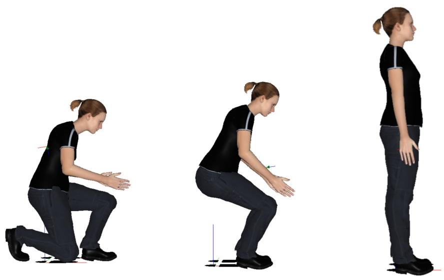
The cube model shows how the combination of posture, time and force may increase or decrease the risk of harmful loading. The model categorizes the severity of the three factors into three risk levels; low risk, moderate risk and high risk, each assigned a value from one to three. By multiplying the scores from all three factors a total risk level is obtained. Risk levels below six is considered as low risk, a risk level between six and eight is considered as a moderate risk and a risk level of nine or above is considered as high risk [17]. Thus, scoring a high risk (three) on only one of the three factors may be an acceptable while a moderate risk on all three factors may be unacceptable and a subject for re-evaluation [12].

2.2.1 Methods of measurements

Physical loads can affect and impact the human body in different ways depending on the anthropometric variations, posture, time, force and more [12]. It is thereby important to measure these in a systematic way to ensure that the assessment of the loads' effect on the human body is accurate. Examples of how these factors, also illustrated in figure 2.2, can be measured follows in the below sections.

Posture is commonly approached by measuring the angular and distance deviations from an "optimal" posture, which provides insights in how the posture is positioned, bent and twisted. The optimal posture, also called neutral body position, has been determined in and compiled in standards (ISO 9241-400:2007) to be the condition where the human body experiences the least tensions and stresses on muscles, tendons, joints and bones [18][19]. The neutral posture is achieved as a symmetrical standing position with arms hanging alongside of the body and head faced straight forward [12]. Examples of body parts and measurements of their deviation against an optimal position have been extracted and formulated accordingly, see table 2.1.

Table 2.1: Table of posture measurement examples.

Examples of body parts and measurements				
Body part	Measurement	Illustration	Measurement	Illustration
Trunk	Flexion/ Extension		Lateral Bending	
Shoulder	Abduction/ Adduction		Flexion/ Extension	
Wrist	Supination/ Pronation		Ulnar/Radial deviation	
Neck	Flexion/ Extension		Axial Rotation	
Stance				

There are two main aspects of **force** to be considered in a physical loading situation of an assembly task. The first and most obvious being mass of a carried or manipulated object by an operator. This aspect of force is typically measured in a rather simple and straight forward manner using ordinary weight scales measured in [kg] [12]. The second aspect is the force applied by the operator in order to perform the assembly task, often related to hand or finger forces, such as tightening a zip-tie, entering a bolt or operating a tool [20]. These forces are more complex to measure and estimate. Unless specified force gauges could be used.

The **time** aspect consists of various exposure factors that can have both a negative and positive impact on the total risk level. In general, these could either increase the physical loading by extending the duration of exposure of the load or decrease the physical loading by allowing for rest and recovery of a particular muscle group [21]. See table 2.2 for an extensive list of the time measurements to be considered in a physical loading situation [21].

Table 2.2: Table of time measurements.

Type	Description
Repetitiveness	Measured as the number of posture changes per shift or time unit.
Frequency	Measured as the number of times a specific muscle group has been activated per time unit.
Cycle time	Measured as the time duration per motion or task.
Recovery time	Measured as the time in between two active stages of a specific muscle group.

2.3 Ergonomic assessment methods

There are multiple ergonomic methods used to assess different scenarios and different kinds of movements. The following subsection presents a few, of which this study has been based on. The ergonomic methods presented below have been based on the literature by Berlin and Adam [12], with a few additional standards that are more industry and company related. However, company standards are normally not scientifically proven [22]. The methods presented in this section originates from different industries and geographical regions, which provides a holistic and diverse view on ergonomic assessments.

In general terms, most of these ergonomic methods can be categorized into one or more out of three categories; Posture-based, Biomechanics-based or a combination of environmental factor-based [12]. Posture-based methods focuses on joint angels and positions while Biomechanical-based methods considers the forces and torques exerted on the body and its joints. Finally, a combination of environment factor-based methods takes into consideration additional factors such as duration, pace, temperature, vibrations etc. In table 2.3, the ergonomic methods chosen for evaluation in this report has been categorized into the three above mentioned categories.

Table 2.3: Table of ergonomic assessment methods.

Methods	Posture-based	Biomecanics-based	Environment-based
RULA	x		
REBA	x		
OWAS	x		x
EAWS	x	x	x
KIM	x	x	x
HARM	x		x
RAMP	x	x	x
JSI	x		x
NIOSH		x	
SARA			
VCS			

2.3.1 RULA

RULA, *Rapid Upper Limb Assessment*, was developed in 1993 by researchers at the University of Nottingham as an ergonomic scoring tool for hand intensive work [12]. The assessment tool provides rapid evaluations of the load on the musculoskeletal system of an operator taking in account the posture, muscle function and exerted forces [23].

Gestures and postures that frequently occur, involve large forces or in other ways are identified as extremes are typically selected for evaluation. Using a "neutral" harmless position of a joint or body part as the benchmark, penalty points are added for the posture deviating for its neutral position on a graded scale, taking in to account legs, trunk, neck, upper arms, lower arms and wrists [23], see Appendix A. Because of the simplicity and rapidness of RULA, it has become a widely used tool as it quickly identifies harmful posturing as well as it is easy to communicate and understand on all levels.

2.3.2 REBA

Following, RULA researchers in Nottingham continued to further develop the method and to create a tool focusing on whole-body intensive work. The result of which came to be REBA, *Rapid Entire Body Assessment.* Developed by researchers at the city hospital of Nottingham its main purpose was for use within the healthcare industry [24]. The REBA method considers the same six body regions as RULA but in greater depth, bringing a larger focus to the lower body regions as well as introducing coupling and griping score [12], see Appendix B.

2.3.3 OWAS

OWAS, *Ovako Working-Posture Analysis System*, as an ergonomic assessment method was developed in the late 1970s, by the former industry steel workers Osmo Karhu and Björn Trappe [25]. The method is based on a simple and systematic assessment of work postures in combination with the present musculoskeletal load. The easily identifiable work postures that are covered in the method concerns the back, arms and the legs [25]. The assessment generates a four-digit index score, where each digit correlates to a posture or load classification [12], see figure 2.3. The index score indicates in what areas the most harmful positions appear, by addressing these with a high score. For the full OWAS assessment sheet, see Appendix C.

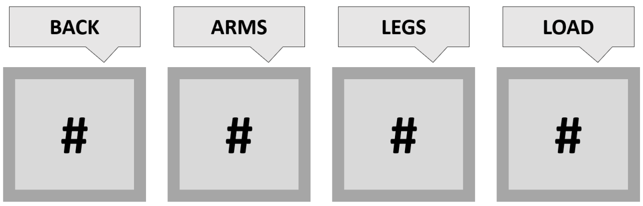


Figure 2.3: OWAS score index with representative digit description, adapted from Loehevaara and Suurnäkki.

The ergonomic assessment method should preferably be performed by the use of equal interval system of either 30 or 60 seconds to observe the operator [25]. The frequencies of the work postures can thereby be calculated from the observation as their relative proportions (%) in relation to the entire working time. The method does hence put a lot of strain on the observer who needs to make validated and accurate assessments during the full observation period [26].

2.3.4 EAWS

Created in the late 00s by the International MTM, *Methods-Time Measurement*, Directorate, the EAWS, *Ergonomic Assessment Worksheet*, standard gives a holistic ergonomic assessment compliant with international workplace standards such as ISO, *International Organisations for Standardization*, and CEN, *European Committee for Standardization* [12]. Postures covered by the tool includes neck, trunk, legs, arms, wrists and hands. In addition to posture and force-analyses, the tool also extends to screen the risks of biomechanical overload as the result of workplace design, production plan and work organization. This is done by considering product variant mix, breaks, working hours and protective gear etc. as a decisive factor in biomechanical overload [27]. Based on a cumulative score of the EAWS assessment sheet, a rating of the evaluated task is presented on a green-yellow-red acceptance scale [12]. A complete EAWS assessment sheet can be seen in Appendix D.

EAWS was created with the automotive industry especially in mind taking advantage of the MTM-study commonly used in the industry. The tool ties each posture and movement to its measured MTM-time, taking the exact consecutive time of exposure into consideration when determining the biomechanical load [27]. Worth mentioning is that the EAWS method should not be considered unless MTM is thoroughly implemented in the organization and an MTM-certificate is obtained by an official MTM Association approved by the International MTM Directorate [22].

2.3.5 KIM

Created by the German Federal Institute for Occupation Safety and Health (BAuA), KIM, *Key Indicator Method*, is designed to assess most cases of manual handling of loads. The assessment is done by observing a workstation and a certain task. The executor of the KIM analysis then grades the perceived posture and work situation by benchmarking the observed task against a predetermined scale defined in the KIM worksheet. It is therefore vital that the observer has good knowledge and insight in the workstation in order to make a fair evaluation [28]. The tool is divided into six independent variants, all covering different type of loads situations occurring in the workplace [28]. Today, the three main variants of KIM used in the industry includes KIM-LHC/PP/MHO, also referred as KIM I, II and III.

KIM I

KIM I, Lifting/Holding/Carrying, mainly analyses load situations that involves different types of manual lifting operations, which includes e.g. picking operations and/or manual transportation of goods [29]. Factors such as exposure time, repetitiveness, load and postures are being assessed in combination with the working conditions, to result in a final evaluation [29]. The final evaluation is the result of adding the score of each assessed factor, which forms a final risk score. The risk score can thereafter be read out from a table which categories the risk from 1 (green) to 4 (red) [12]. The full ergonomic assessment sheet for KIM I can be read in Appendix E.

KIM II

KIM II, Pushing/Pulling, mainly analyses load situations that involves different types of manual pushing and pulling operations, which includes e.g. pushing a trolley and/or pulling a pallet jack [30]. Factors such as exposure time, repetitiveness, load and postures are being assessed in combination with the working conditions, to result in a final evaluation [30]. The final evaluation is the result of adding the score of each assessed factor, which forms a final risk score. The risk score can thereafter be read out from a table which categories the risk from 1 (green) to 4 (red) [12]. The full ergonomic assessment sheet for KIM II can be read in Appendix F.

KIM III

KIM III, Manual Handling Operation, mainly analyses load situations of manual handling, which includes e.g. assembling packages and/or other hand intensive tasks [31]. Factors such as exposure time, repetitiveness, load and postures are being assessed in combination with the working conditions, to result in a final evaluation [31]. The final evaluation is the result of adding the score of each assessed factor, which forms a final risk score. The risk score can thereafter be read out from a table which categories the risk from 1 (green) to 4 (red) [12]. The full ergonomic assessment sheet for KIM III can be read in Appendix G.

2.3.6 HARM

As an initiative to promote and maintain public health in in Holland the Dutch minister of Ministry of Social Affairs and Employment launched in 2007 an initiative to develop a set of free risk assessment tool for its companies nationwide, one of these tools made available in 2009 is HARM, *Hand Arm Risk Assessment Method* [32]. The HARM tool is especially designed to evaluate work tasks prone to cause neck-, arm-, and shoulder pain as a result of hand intensive tasks such as assembly or picking operations [32]. The assessment is made by observations and interviews with the operator and takes into consideration the posture, exerted forces and duration of exposure in combination with organizational and environmental aspects such as brakes and temperature. A cumulative score of the work tasks risk score is presented on a on a green-yellow-red acceptance scale. See Appendix I for a complete HARM assessment sheet.

2.3.7 RAMP

Developed by researchers at KTH Royal Institute of Technology in Sweden, RAMP, *Risk management Assessment tool for Manual handling Proactively*, as an ergonomic assessment method aims to evaluate and manage MSD risks in manual handling operations [33]. The tool is a compilation of knowledge obtained from research studies, experiences, legislation and other ergonomic methods and standards, and was digitally launched in 2017 [34]. Developers has in RAMP implemented the functionality of providing the users of the method with examples of improvements based on the ergonomic assessment. The assessment can be done at two stages, RAMP I and RAMP II, and is made by completing a digital evaluation sheet, which analyses postures, movements, frequency, loads, type of work, together with other influencing factors [12][35]. The first stage is more of a screening assessment whilst the second stage is more in-depth analysis [12]. After making evaluations of these parameters, an accumulative score will result in an overall risk score, which presents the risk assessment at three levels; red (high risk), yellow (medium risk) and green (low risk) [35]. The full ergonomic method of RAMP II is presented in Appendix J.

2.3.8 JSI

The JSI, *Job Strain Index*, standard was developed by researchers at Cornell University in 1995 and is a paper-based assessment sheet designed to evaluate the risk of MSDs as a result of hand intensive work tasks [36]. The standard takes into consideration six aspects; the intensity of exertion (IE), duration of exertion (DE), efforts/minutes (EM), speed of work (SW), duration per day (DD) and hand/wrist posture (HWP). Some of the above mentioned factors need to be subjectively analysed by the observer thus the standard might be prone to bias [36]. The final scoring is obtained by multiplying the six factors and is presented on a green-yellow-red acceptance scale [12]. See Appendix K for the complete JSI assessment sheet.

2.3.9 NIOSH

The National Institute of Occupational Safety and Health (NIOSH) Lifting Equation was initially introduced in America 1981, revised in 1994, and has since then as a tool been frequently used by ergonomists to assess lifting tasks [37][38]. The method considers a number of parameters which concerns load constant, horizontal and vertical multiplier, distance, etc., to calculate the Recommended Lifting Weight (RWL) by multiplying the factors together [12].

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \tag{2.1}$$

```
RWL = Recommended Weight Limit ,  LC = Load Constant
HM = Horizontal Multiplier ,      VM = Vertical Multiplier
DM = Distance Multiplier ,        AM = Assymetric Multiplier
FM = Frequncy Multiplier ,        CM = Coupling Multiplier
L = Load Weight (proposed) ,      LI = Lifting Index
```

Thereafter, a Lifting Index (LI) can be calculated from the products of the RWL equation, as follows:

$$LI = \frac{L}{RWL} \tag{2.2}$$

The result from the tool assessment can be interpreted as a risk analysis, where the risk is defined as a combination of the probability of occurrence and harm [39]. The RWL is defined as the weight which can be handled by the majority of healthy people during the working day [12]. If a weight were to exceed the recommended weight limit, the work task needs to be further investigated and changed as it can cause anthropometric and ergonomic injuries.

2.3.10 SARA

Originally developed at SAAB automotive in 2002 the SARA, *Samlad Riskbedömningar Arbetsplatser*, standard provides an overall risk evaluation of the work environment considering seven aspects; Noise, Lightning, Thermal conditions, Fire hazards, Risk of Accidents, Machine safety and Ergonomics [40]. The tool is excel-based and made up of a number of yes and no questions to be answered based on observations of the workstation and task, generating a score on a green-yellow-red acceptance scale [40]. The ergonomic aspect of the SARA standard handles both full body posture as well exerted forces and duration of exposure. Being developed as the main standard within SAAB automotive the ergonomic component in SARA takes on a holistic perspective as it is to be used in all parts of SAAB's operation. Thus, it treats ergonomics in a general way without emphasize on a particular area of harm [40]. See Appendix L for the complete SARA ergonomic assessment sheet.

2.3.11 VCS

Known for their devotion towards safety, Volvo Cars developed their own ergonomic guidelines with the same intent, VCS, *Volvo Cars Standard*. The company specific ergonomic standard for physical loading is designed with Swedish and European directives in mind as well as giving a holistic view on the entire operation, covering both assembly and logistics [41]. The standard takes in account the workplace and product design, such as work posture, exerted forces, aids and vibrations as well as organizational factors such as work rotation and workload etc. [41]. Being a general standard applied on most parts of the operation, it could be argued that it does not put any deeper emphasize and clarification on particular areas. As for posturing, the standard fails to recognize all parts of the body, leaving some areas exposed to harm. It is also unclear how the standard deals with different anthropometric data as some of its measurements and guidelines are only given based on the average measurements of an adult male and female. Furthermore, the standard does not provide any grading system or final result of the workplace as it is rather used as a guideline of how not to design the workplace or task. This leaves the standard prone for bias as well as creates difficulties when communicating or arguing for the sake of ergonomics. Hence the standard is often used as a complement to some of the other standards used in the industry e.g. KIM. See Volvo Car Corporation standard (VCS 8003,29) for the complete VCS document.

2.3.12 Geely

The ergonomic standard conducted by the Manufacturing Engineering Department at Zhejiang Geely Holding (Group) Co., Ltd., was both issued and applied during 2019. The standard specifies four types of plants; stamping, welding, coating and final assembly [42]. Depending on what plant is assessed, the standard has predetermined a number of settings that affects the overall evaluation score. By addressing 13 different dimensions, including e.g. visibility, environmental factors, posture, installation space, force, and repetitiveness, the method will result in an accumulated evaluation score between 0 and 300 [42]. However, depending on what plant is specified, all the 13 dimensions may or may not be assessed. For instance, by evaluating work in a weldshop, the standard does not consider repeated operations of the operator's wrists, as it would if another workshop were to be evaluated. The reason for this could be that the operator is ought to not have any repetitiveness in the wrists for such an operation. How well this correlate to reality, is not issued by the standard. The final score of the standard will result in the total ergonomic status accordingly:

- Score $<$ 100 pts: Good ergonomics
- 100 $<$ Score $>$ 200 pts: General ergonomics
- Score $>$ 200 pts: Poor ergonomics

As the method concerns multiple criteria, the standard provides a holistic grasp of the ergonomic situation at the workstation. Although, by having the score system of the 13 different dimensions in an accumulated fashion, in theory, the assessment could be good for the majority of criteria and unacceptable for a few - and still result in a positive ergonomic outcome. Furthermore, it is unclear how the anthropometric and demographic data are covered in the standard, as some guidelines are based on average measurements. For instance, the criteria regarding finger installation space does not include the size of a person's finger, rather than solely the size of the space [42].

2.4 Digital Human Modeling

DHM-software are tools for analyzing, simulating and evaluating human movement and interactions with products and processes in a digital environment. By working with virtual human models or manikins representing anthropometric data of a particular demographic, and exposing these to objects and tasks, parameters such as reachability, accessibility and ergonomics can be assessed at an early stage [12].

2.4.1 IMMA/IPS

IMMA is one of many DHM-applications used by the industry worldwide. Developed by Fraunhofer-Chalmers Center, it is the result of a collaboration between major Swedish manufacturers and academia [43]. IMMA aims to reduce simulation and analysing time as well as minimizing biomechanical load in the workplace by introducing intelligent path planning and movements of its manikins [43]. IMMA has been introduced as a part of the simulation software IPS.

In IPS, the IMMA can be imported either as a single manikin or as a member of a family representing an anthropocentric data set. The size of each family then varies depending on the preferred percentile or demands determined by the user.

Kinematics

The kinematic model of IMMA is built to mimic the human skeleton in an accurate, yet simple way. The 207 human bones structures have been narrowed down to a kinematic model composing of 82 bones, providing the IMMA manikins with a rigid structure capable of taking on any anthropocentric shape and form [44]. In between each bone, 162 joints connect the segments into a skeleton structure. Together, one bone segment and one joint form a link, govern by a translation, rotation and a mass. The translation of the link determines the length of the bone, the rotation determines the axis as well as degrees of freedom and the mass determines the weight of the represented body part [45]. Each joint is two-dimensional capable of rotating around one axis. The two-dimensional joints are proven optimal to mimic two-dimensional body movement such as an elbow or a knee. However, in the case of more complex body parts that requires a three-dimensional joint, such as a shoulder or a hip, two two-dimensional joints are interlinked in a chain structure to give the impression of a three-dimensional rotation [45]. This allows the joints to rotate in either one (x), two (x, y) or three (x, y, z) dimensions.

Overlaying the kinematic model is a rendered mesh representing the outer shell and the appearance of the manikin. The mesh gives the manikin its human looks and characteristics and is together with the kinematic model based on anthropometric data representing a particular workforce, see figure 2.4. Meaning that measures of the kinematic model varies with the anthropometric dataset chosen by the user.

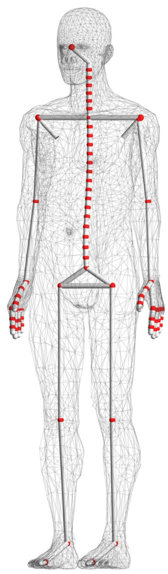


Figure 2.4: The joints and surface mesh of a manikin, provided by Fraunhofer-Chalmers Centre.

Kinematic motions

Motion of the manikin is governed by a series of control points, normally placed in the hands and feet of the manikin. Each control point resembles a TCP, *Tool Center Point*, with a corresponding target frame [45]. In a static position the translation and rotation of the target frame matches that of the TCP of the control point, but as the target frame is moved away from the TCP, a motion in the manikin is triggered as the TCP tries to link up with the target frame. Rotations and translations of the joints and links in the kinematic model is calculated and based on the relation to the control point using inverse kinematic resulting in the manikins taking different poses [46]. Thereby, solely placing a fingertip of the manikin at a certain position, the rest of the consisting joints will align and re-position to match the fingertips target position. This is illustrated in figure 2.5 [46]. Consequently, this procedure works for all the joints in the IMMA model.

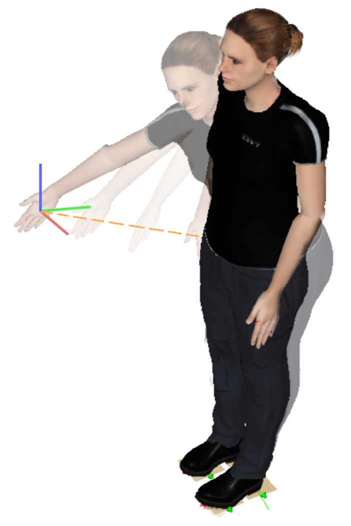


Figure 2.5: Illustration of the inverse kinematics of the IMMA-manikin in IPS, own picture.

In order to simulate and replicate a human's body movement, the intelligent manikin needs to physically be able to perform certain complex tasks. This includes the ability of grasping objects with different grips, bending and twisting with pronation, flexion, ulnar deviation, etc..

Pathfinding through IPS is constructed to move an object from one point to another, in the shortest possible distance without making any collisions [43]. This includes any rigid body and static objects in the scene, as well as the movement of the manikin [43]. There are currently multiple different pathfinding solutions being used, each one more or less suitable for particular tasks. In general, pathfinding algorithms tries multiple different routes between two points, and then chooses the shortest, simplest or cheapest - collision free movement between these points [47]. Such criteria are dependent on how the algorithm has been structured and could also include requirements of for instance going through a third point C [47]. The following figure 2.6 visualises a simplified pathfinding solution of navigating a maze, finding the shortest distance between point A and point B.

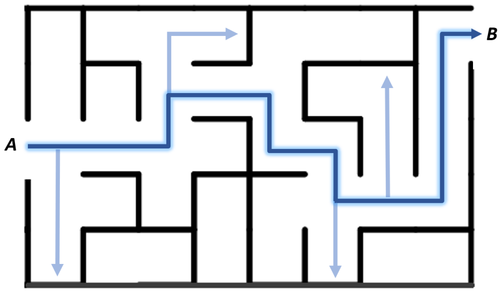


Figure 2.6: Pathfinding solution visualising the shortest collision free route between point A and B with a clear blue line, own picture.

Comfort function

IMMA uses inverse kinematics and computational methods to predict and generate the most ergonomic posture of the manikin in relation to its assigned task. This is within IMMA known as the comfort function [48][46]. By limiting the manikin to a few constraints, e.g. heels on the floor, 50 mm clearance to any object and grasping with the left hand, an optimization algorithm calculates and adjusts the joints of the manikin in relation to the constraints to achieve the most comfortable posture [48][44]. The comfort function takes into consideration the comfort of each joint as well as the balance and equilibrium of the manikin [48]. Each joint's optimal position is based on its neutral position considering the rotation axis as well as the applied torque in that particular joint [45], see figure 2.7.

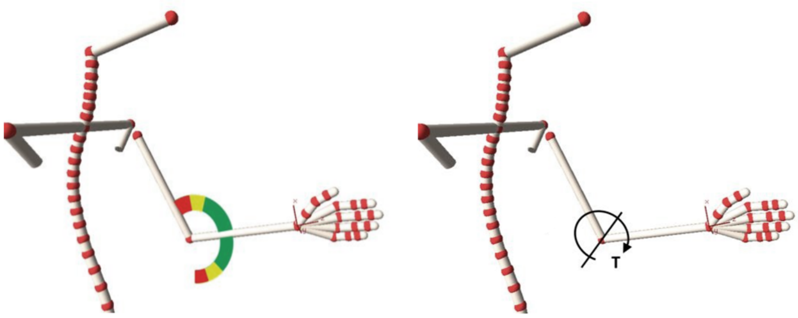


Figure 2.7: Illustration of joint comfort model factors, adapted from Mårdberg.

The comfort function of IMMA in combination with the pathfinding solution in IPS enables the manikin to generate collision free and ergonomic acceptable motions in a complex environment. This eliminates the need for manually defining every single movement and posture of the manikin [49]. Instead high-level tasks could be defined directly, leaving the manikin and the software itself to predict and perform the movements and postures accordingly in the most ergonomic and sane way [49].

2.4.2 Ergonomic function in IMMA

A previously made ergonomic analysis function already existed in IPS prior to the start of the thesis. This function was solely based on the RULA ergonomic assessment method and graded the ergonomics of the manikin as such. By calculating the manikin's posture based on a predetermined set of joint angels as well as posing two complementary questions to the user, an overall RULA score could be presented, see figure 2.8.

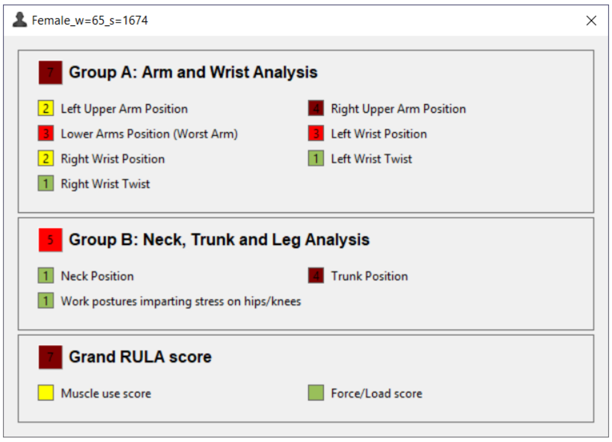


Figure 2.8: Representative grading score of RULA assessment in IPS, screenshot form IPS software.

The function was however limited as it lacked the possibility of customization for particular industries, company standards or other ergonomic assessment methods. It has thus currently not been used to the extent that it could have been, as it is not fully cohesive with the company standards and way of working at CEVT.

2.4.3 Scripting in IPS

There are several ways to program or add functions in the IPS software. In the case of ergonomics functionality, two main ways to conduct such a function was identified; customizing the already existing ergonomics functionality using *JSON*-scripting, *JavaScript Object Notation*, or by creating a new functionality using *LUA*-scripting with available API, *Application Programming Interface*, for IPS and IMMA [50].

JSON

The already existing RULA ergonomic assessment function in IPS has the ability to be modified to some extent using JSON-scripting. The functionality allows for 24 different joints to be monitored and scored on a green-yellow-red acceptance scale with customized conditions and limits based on its rotation and cumulative time. The available joints for monitoring through the existing functionality are presented in figure 2.9.

Since the existing functionality is entirely based on RULA, the final visualized report as well as the final score will be presented and calculated accordingly. Hence the visual appearance of the report can not be customized as well as the underlying calculations of the final score. Meaning that any added or customized joints or function could only be rated separately without affecting the total score. This will in return make any kind of overall assessment implausible.

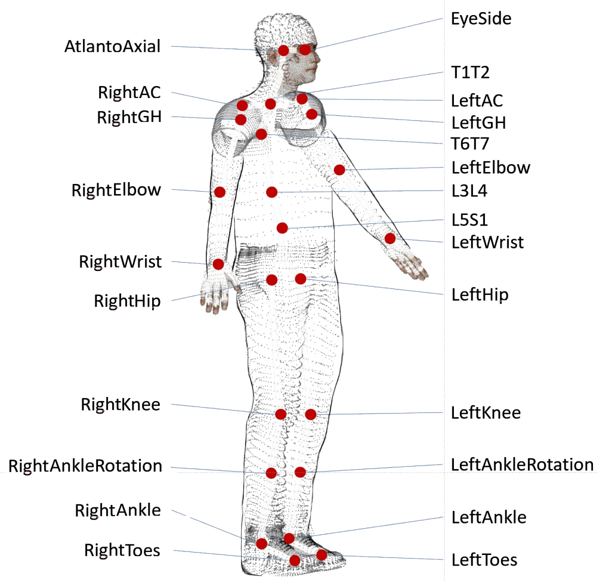


Figure 2.9: Illustration of the IMMA and the joints that are available to be called in JSON, from IPS documentation provided by Fraunhofer-Chalmers Centre.

LUA

Scripting custom functionality in IPS is done through a programming language called LUA. Using LUA in combination with the available API for IPS and IMMA would allow for a higher degree of customization than compared to the JSON alternative. The API enables monitoring of the rotation and translation of most of the joints in the manikin as well as gathering additional data by user input [50]. Calculations and algorithm of an overall score would also be possible no matter the ergonomic assessment method of choice. However, the API lacks support for GUI, *Graphical User Interface*, or reporting capabilities [50].

3
Methods

In the following section, the methods used in the project will be covered and explained in detail. The methodology follows a clear structure and framework used during the project. The framework centers around finding, screening and benchmarking suitable ergonomic evaluation methods with the final aim of reaching a decision of implementation of one or more ergonomic methods or standards. Furthermore, methods regarding the implementation as well as verification and validation through case studies will be presented.

The methodology framework has been structured and divided into four phases, see figure 3.1. The customized framework was inspired by Jamal Starr's article: "*The four stages of successful benchmarking*" and thereafter modified to this particular project [51]. The four stages of the methodology framework constitute the subheadings of the chapter.

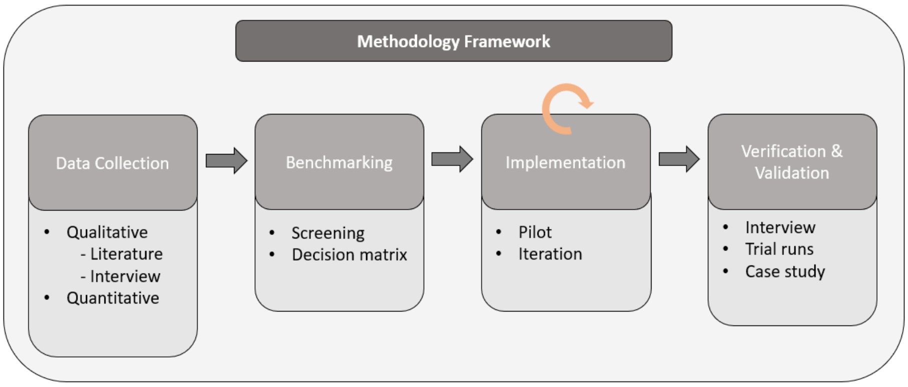


Figure 3.1: Framework of the project outline, based on Starr and modified by Leonard Bogojevic.

3.1 Data collection

In order to gain a deeper theoretical understanding of the problem as well as creating a foundation of knowledge of which to base the project on, a data collection phase was commenced early on. The data collection phase has been divided into a qualitative and a quantitative data collection part.

3.1.1 Qualitative data

The qualitative data was mainly collected from the extensive literature and interview studies. Relevant subheadings have in this section been made to structure and simplify the reading of the section.

Literature

An iterative literature study was completed to provide insight in what potential solutions should be considered or neglected in the project. Relevant delimitation was seen beneficial in order to increase the so called value-adding time, whilst not wasting resources on solutions that were already confirmed to not be feasible to implement. The study focused on different parts of the project, considering both ergonomic and DHM related aspects.

At early stages, a benchmarking list of how different ergonomic assessment methods correlated to IPS functions was extracted based on a literature study. The list was made to eventually be transformed into a matrix, visualizing the different evaluation methods and its criteria that they consider. The matrix would then show how these criteria correlates to the functions in IPS, meaning which factors can or cannot be automated in the IPS simulation. The methodology of the extraction was done accordingly; *1. Finding potential ergonomic evaluation methods/standards to use. 2. Eliminate methods/standards which are not relevant to the case. 3. Allocating the methods/standards and their characteristics. 4. Matching the properties of the methods/standards to the IPS functions. 5. Display in a benchmarking matrix.* Further delimitation on the benchmarking matrix was done to finally result in a single method/standard which would be seen as the most optimal solution to implement.

Interviews

In order to obtain significant knowledge and understanding in the fundamentals of the project, the group conducted multiple interviews with relevant stakeholders of this project. The central interviews with particular relevance to the study involved software developers and ergonomists from both industry and academia. The interviewees were determined after the basis of the literature study had been obtained, as the group had gained experience in what questions needed to be addressed and further investigated. The interviewed persons were stakeholders that had been encountered during the literature study, as e.g. authors or internal and external stakeholders. At an early stage in the project, the potential interviewees were contacted, with a request of participating in an interview. The interview candidates were contacted by e-mail with 1-2 weeks' notice, to allow for some response and planning time. All interviews were recorded and transcribed after agreement of the respondents.

As a part of a qualitative study, multiple interviews with Niclas Delfs and Elin

Fägerlind at FCC were conducted over time. Delfs and Fägerlind are a part of the developing team that works with the IPS IMMA tool and could thus provide an understanding of how the simulation and the programming behind the actual tool worked. Delfs is a researcher and developer of the IMMA tool with good insight of its functions and context. The initial interview with Delfs and Fägerlind worked as background to the simulation where they explained the basic fundamentals of the program. Further interviews were set up semi-structurally, with relevant questions asked to the respondent who was allowed to answer the questions generally or give a more elaborate and precise answer. These relevant questions were formulated after the group had encountered uncertainties in the programming layout or other simulation-related issues. The strategic structure was decided to open for good discussions with the respondent and hopefully work as a good input to discussion, conclusion and future work. All interviews with Delfs and Fägerlind were performed in person at FCC's facilities.

Further on, an internal ergonomic expert within the company as well as an academical ergonomic expert were also contacted and interviewed. Agneta Figaro from the ME department at CEVT, was interviewed in a semi-structured fashion, to provide information and knowledge in how ergonomic assessments are currently performed at CEVT. An interview with Cecilia Berlin, Associate Professor at the division of Design & Human Factor at Chalmers University of Technology, was also conducted in a similar fashion as Figaro's, but with the aim of getting exclusive understanding in what ergonomic evaluation methods may or may not be suitable for this particular case. The interviews were performed at CEVT's office respectively at Chalmers University of Technology.

Dan Lämkull, global strategy manager of ergonomics at Volvo Cars was also interviewed at an early stage of the project. Lämkull had been recognized in many of the considered articles that composed the literature study and had thus been part of many projects with the scope similar to this. A semi-structured interview was performed with Lämkull at Volvo Cars Torslanda, with a focus of getting support and knowledge in potential work methods. As Lämkull had been part of similar projects before, he possessed knowledge in what factors should be neglected and what should be further investigated.

Furthermore, a telephone interview with Michael Schröder from Volvo Group was conducted during the first half of the project. Schröder is a certified European ergonomist with good knowledge and insights in common work-related injuries from assembly operations. The aim of the interview was to obtain valuable information that could work as support in the decision matrix of what ergonomic evaluation method to implement to IPS.

To obtain a better understanding and knowledge regarding the IPS software and the functions available in the program, an IPS IMMA Training Day was attended at the University of Skövde. This also entailed relevant interviews and discussions with experienced people within IPS IMMA, as well as with ergonomic understanding.

Aitor Iriondo Pascual, PhD student from the University of Skövde was of particular interest as he was part of a similar project concerning ergonomic methods in the IPS IMMA tool as well. A spontaneous interview with Aitor was thereby held on place.

3.1.2 Quantitative data

Quantitative data was collected during the literature and interview studies with the aim to support any decision regarding the selection of ergonomic evaluation method for implementation. It was argued that data and statistics that addressed the health and MSD among operators in the industry could act as great input and support a future decision. Therefore, data was collected among interviewees of relevance. Statistical data bases such as Statista as well as data sets provided by the Swedish work environmental authority were also consulted with the intention of pin pointing cause and effects of MSD within the industry.

3.2 Benchmarking Process

The benchmarking process includes both mapping and screening of the ergonomic assessment methods. The different methods to include in the benchmarking process was based on a selection from the data collection study. These methods where then compared and evaluated in the screening process.

3.2.1 Screening process and decision matrices

In order to select a final ergonomic assessment method to implement into IPS IMMA, multiple alternatives needed to be considered. By comparing multiple relevant alternative solutions to each other, a screening process could be particularly beneficial in terms of bringing forth the most suitable solution [52]. The alternative solutions to include in such a screening process was decided from the data collection study, including alternatives which main focus relies on posture analysis and are commonly used in either automotive industry - or in any other relevant industry.

The comparison process has been carried out through a number of steps, including different types of decision matrices with input from qualitative and quantitative data gatherings. Initially, a more general comparison matrix was conducted to clarify each methods' characteristics and illustrate how those compares to the other methods. A second matrix included how these correlates to IPS functionality, to provide a sense of complexity. The result from these initial matrices, together with input from statistics and qualitative data, would act as a good ground to base the selection decision on. The final alternative solutions were evaluated and weighted in a Kesselring matrix, where a final solution could be selected.

Comparison matrix

Following the decision-making methodology proposed by P. Newton and H. Bristoll, a first step in any screening process should consist of mapping possible candidates and cross-linking these against the defined influential factors intermediate in the decision [52]. In ordinance with this a comparison matrix was seen as beneficial.

Based on the data collection study, a number of ergonomic evaluation methods of interest was found. These were through a profound literature and interview study deeper analysed, the result of which was presented in a comparison matrix. The comparison matrix maps and cross-links the time, force and postural factors taken into consideration by each ergonomic evaluation methods of interest. This gives an overview of which method covers which aspects and to what extent, pinpointing clear discrepancy and characteristics of each ergonomic evaluation method. The comparison matrix was produced with input from the data collection phase and theory presented in chapter 2 - *Theory.*

Complexity score

As part of the screening and benchmarking process each ergonomic method was evaluated based on their complexity and scope. It was brought to the authors' attention that a more complex and detailed method would most likely cover a wider perspective of ergonomics and possibly bringing extended value to the simulation [22]. In regards of this, each method was assigned a complexity score based on the number of factors taking into consideration during its evaluation phase. Based on the comparison matrix a cumulative sum of posture, time and force criteria covered by each method was given as a reference of its complexity. Giving indications of its consistency with the cube-model as described in chapter 2 - *Theory.* A higher cumulative score indicated a larger amount of detail and complexity of the method whilst a low score indicates a lower degree of criteria influencing the assessments thus making it less complex.

In combination with the complexity score a second quantitative score was assigned to each evaluation method. This score was based on the corresponding criteria of each method that could be tracked and measured by the already existing ergonomic analyse tool embedded within IPS. This provided an overview of the complexity of implementation of each method and to what degree each method could be automated using the IMMA/IPS tool. A high score indicates a high correlation between the IPS capabilities and the assessment methods criteria of measurements thus lower complexity of implementation.

Kesselring matrix

In order to reach a decision and find the most optimal ergonomic-method for implementation a decision-matrix was created. The decision was made to use a weighted Kesselring-matrix in order to put emphasis on aspects deemed crucial and of most importance, as proposed by the methodology introduced by P. Newton and H. Bristoll [52]. The matrix rates how well each ergonomic evaluation method fulfils a certain set of criteria [53]. Each criterion is assigned a weighted score between one to five representing its importance and relevance for the decision. Meanwhile each ergonomic evaluation method is rated and given a score between one to five on how well it fulfills the corresponding criteria. The score achieved by a specific ergonomic method relative a certain criterion is the product of its weight and the rated score [53]. Finally, a total score based on the sum of all criteria score is assigned to each contested alternative and the alternative with the highest total score would be the subject for decision.

The scores and weights presented in the Kesselring matrix were decided partly based on the authors perception, but also based on statistics and data and in consensus with the ergonomist at CEVT. Hence, if a method considers more aspects from e.g. a specific body part posture, it would thus result in a higher score. For instance, if one method considers both flexion/extension and radial/ulnar deviation of the wrist, while another method only considers flexion/extension, it would be given a higher score since it considers more factors. The weights corresponds to what parameters are more or less important to the specific implementation.

3.3 Implementation

Once the decision of an ergonomic evaluation method was reached based on the screening methodology described above, the implementation of the functionality into IPS IMMA was commenced. The implementation phase of the project was structured in an iterative way leading to incremental development of the functionality. The iterative process followed the methodology of the PDCA-cycle, proposing a four-step iteration, see figure 3.2 [54].

Figure 3.2: PDCA-cycle representing the framework of the iterative implementation process, adapted from Skhmot by Henrik Söderlund.

The iterative approach allowed for continuous improvement and adding functionality and improvements as the project unfolded, resulting in an incremental development [54]. Each cycle allowed for pilot testing at separate stages of the project and functionality could be evaluated continuously.

Different ways of development were also discussed as different solutions of how to tackle the task became obvious during the literature and interview study. For instance, solutions using the built-in ergonomic functionality in IPS, extracting data to a third-party software or development of own add-on functionality in IPS were discussed. The different potential solutions were analysed reflecting upon the pros and cons of each solution resulting in a decision and chosen method.

During the entire implementation process, a continuous dialogue was held with the primary stakeholders in order to keep them in the loop. This was done to ensure that the implementation and the resulting interface was done according to their requirements and standards. Reasonable compromises were able to be reached for those parts of the implementation that needed to be re-arranged. The relationship with the identified stakeholders was early in the project recognized to be very important. Therefore, the key stakeholders were managed through the right amount of communication and deliveries, in order to bring value and be beneficial for the sake of the project [55].

3.4 Verification and validation

In order to ensure that the results of the project were truthful and credible, a verification and validation stage was seen essential. Multiple methods were planned to be used to make sure that the implemented function would be both verified and validated. The methods used to verify the function included debugging the code as well as letting others read and test the file, to ensure that there were no errors in the program. The methods to validate the function contained interviews with ergonomists, case studies of both existing and complete cases and trial runs. These methods were seen both relevant and appropriate to apply in this particular project, as the implementation of the project deals with mostly simulations.

The case studies were carried out by comparing two ergonomic assessments to each other, one that had been done manually by an ergonomist at CEVT and the other which had been done through the implemented function in IPS. This was conducted by setting up a simulation that correlated to an actual case that the ergonomist at CEVT had previously or was currently working with. By comparing the results of the two assessments, it could be clear whether or not the function was accurate or not, and it could thereof also be found where the function differed - if necessary. Multiple case studies were conducted.

Due to confidential reasons, only a handful of the presented cases could primarily be considered, before being selected for validation. The cases that were completed during the validation were thereafter selected in consensus with the ergonomist at CEVT and with the aim of covering all stages of the decided ergonomic method, that is green - yellow - red.

4

Results

The results presented in this chapter focus on giving answers to the completed methods. The chapter has been structured with relevant subheadings and paragraphs. The structure of sections correlates to the chapter of the methodology of the project.

4.1 Data collection

Results that concerns the data collection phase is presented in this section. Qualitative and quantitative data has been separated to give a clearer understanding of the results.

4.1.1 Qualitative data results

The qualitative data output has mainly been extracted from performed literature and interview studies. Interviews with different knowledgeable people, each whom could be considered an expert within their own field, was conducted to gain a broad perspective of inputs to the project. The literature study provided great insights in how the research could be focused on certain areas and what parts should be neglected, due to various reasons.

Literature

The literature study resulted in a compiled list of all the ergonomic evaluation methods taken into consideration, presented in table 4.1.

Table 4.1: Table of the ergonomic assessment methods and standards evaluated in the benchmarking process.

1.	EAWS	8.	NIOSH
2.	GEELY	9.	OAWS
3.	HARM	10.	RAMP
4.	JSI	11.	REBA
5.	KIM I	12.	RULA
6.	KIM II	13.	SARA
7.	KIM III	14.	VCS

The factors taken into consideration by each assessment method or standard and their relations to the existing functionality in IPS IMMA, makes up for the foundation of a comparison matrix, see section 4.2 - *Benchmarking process*. The results of the literature study also make up the fundamentals of which the theory section, see section 2 - *Theory*, has been based upon.

Interviews

The interviews provided valuable information regarding both ergonomic and DHM related aspects to the project. Sum and substance of the conducted interviews has been documented, see table 4.2, including the most general outputs from the different interviews.

Table 4.2: Table of interview results.

Respondent	Organization	Sum and substance
Agneta Figaro	CEVT	- Input in how ergonomic evaluations are conducted and performed at CEVT, providing insights in what way the results of this project could be beneficial.
Cecilia Berlin	Chalmers University of Technology	- Valuable information related to the ergonomical aspect of the project, including recommendations of potential methods and standards to investigate. - Information of i.a. relevant academic literature to the project, as well as general tips on how to approach the subject in a beneficial way.
Niclas Delfs & Elin Fägerlind	FCC	- Valuable information related to IPS and IMMA, including insights in limitations and possibilities of the software. - Guidance and supervision of the development of the ergonomic evaluation implementation.
Dan Lämkull	Volvo Cars	- Data of work-related injuries at Volvo Cars. - Valuable tips and recommendations regarding *do's* and *don'ts* in both IPS and in the evaluation.
Michael Schröder	Volvo Group	- General data of the most common injuries at the assembly stations in their factory. - Information and feedback regarding aspects that would be interesting to include in the implementation of the ergonomic assessment tool to the software.
Aitor Iriondo Pascual	University of Skövde	- Practical information and recommendations regarding how the ergonomic evaluation methods could be implemented in IPS IMMA.

Moreover, the respondents provided concise information and recommendations about the subject. The following section mentions the more concise and general output of the conducted interviews.

Cecilia Berlin
Berlin did during the interview underline some important aspects that should be taken into consideration when implementing an ergonomic function, such as displaying the results of a complete manikin family and not only for a single manikin. Moreover, Berlin provided useful information of i.a. relevant academic literature to the project - as well as general tips on how to approach this subject in a beneficial way.

Key take-aways
- Most work-related MSD injuries at an assembly line are related to hands/wrists/arms/shoulders.
- A DHM implementation should preferably include more complicated posture assessments.
- KIM I, II and III gives a holistic analysis of the combination between time, force and posture.

Niclas Delfs and Elin Fägerlind
Multiple interviews were conducted with Niclas Delfs and Elin Fägerlind at FCC. They both provided great information within their IPS IMMA and programming expertise. The first interview consisted of Delfs going through the IPS program as showing underlying code of the already consisting IMMA ergo-methods. The correspondents were then allowed to ask any arising questions directly to both Delfs and Fägerlind.

Key take-aways
- Implementation of an ergonomic assessment method to IPS IMMA should preferably be done internally either through JSON or LUA-scripting.
- Explained the functions and possibilities of making customized IPS tools.

Dan Lämkull
Lämkull provided valuable information and feedback regarding aspects that he thought was interesting to include, but also neglect, in the implementation. He also provided general data of the most common injuries at the assembly stations at Volvo Cars; related to the wrists, arms, shoulders and the back.

Key take-aways
- Most work-related MSD injuries at an assembly line are related to hands/wrists/arms/shoulders.
- Strains on hands and wrists are particularly at risk during clip and harness assembly.

Michael Schröder
Schröder provided valuable information and feedback regarding aspects that he thought was interesting to include in the implementation. Schröder also provided his thoughts and insights of the most common injuries at the assembly stations at

Volvo Group; related to the wrists, arms, shoulders and the back.

Key take-aways

- Most work-related MSD injuries at an assembly line are related to hands/wrists/arms/shoulders.
- Simulations of ergonomic methods should never fully replace the physical assessments, but solely work as a complement and/or be used to give a first insight in the ergonomic risks.

4.1.2 Quantitative data results

The quantitative data has been extracted from the performed literature studies as well as from the conducted interviews. The quantitative data mainly concerns common MSD injuries related to assembly stations. Relevant subsections have been made to structure and simplify the outline of the section.

MSD data

Volvo Cars, as well as many other manufacturers, keeps record over the health and well-being of its staff [56]. This record includes i.a. data of work-related MSD among its staff. As the result of the interviews conducted with Lämkull at Volvo Cars parts of this data was made available for the sake of the project. The data collected shed light on the causes and effect of MSD in the industry. See table 4.3 for an overview of reported MSD injuries at final assembly at Volvo Cars manufacturing plant in Torslanda.

Table 4.3: Table of reported injuries during final assembly at Volvo Cars, Torslanda.

Year	Number of reported injuries	Number of reported hand-injuries
2016	124	61 (49%)
2017	198	94 (47%)
Total	322	155 (48%)

The data quickly showed that about half of all MSD injuries reported during the final assembly at Volvo Cars were hand related injuries. Furthermore, the data unveiled that 66% of all hand related injuries were the effect of high pressure forces applied by the operators during the assembly phase, see figure 4.1.

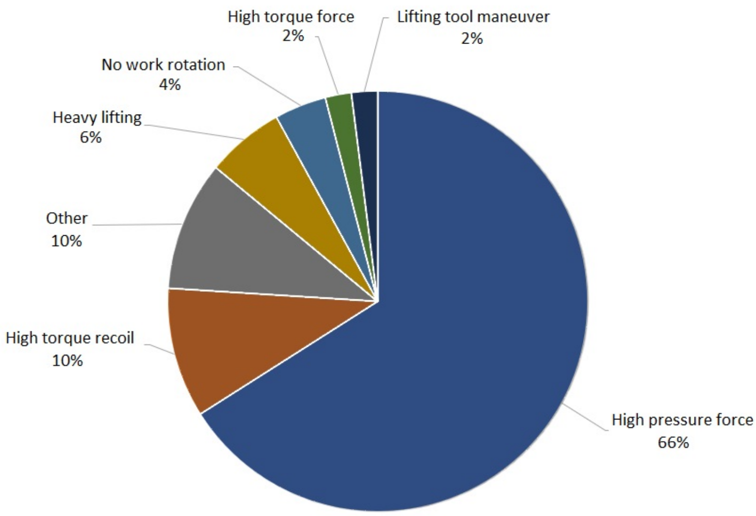


Figure 4.1: Quantitative data listing the causes of MSD in hands at final assembly at Volvo Cars, adapted from Lämkull.

This data was also solidified during the interview with Lämkull as he explained the huge ergonomic impact of clip assembly and the high forces behind harness assembly. This was something he saw as an increasing threat as the electrification of the automotive industry keeps increasing with more hybrids and electric vehicles being produced [56].

The data showed that hands were in particular prone to MSD as a result of high pressure forces, something that was used in the later stages of the project to support the decision of selected ergonomic evaluation method. Methods taking hands and upper limbs into extra consideration were thus deemed more valuable and interesting in the forthcoming of the project.

4.2 Benchmarking process

In the following section the results of the benchmarking process will be presented. The benchmarking process discloses the screening process of the identified ergonomic evaluation methods of interest and the final decision of ergonomic method for implementation into IPS. This section follows the framework previously presented in chapter 3 -*Method* and is divided per the three screening and benchmarking methods used.

4.2.1 Comparison matrix

The comparison matrix resulted in a compiled list of eleven ergonomic evaluation methods and three company standards of relevance and interest, see figure 4.2. The evaluation methods and company standards are explained more in detail in chapter 2

- *Theory.* All of the in total 14 methods and standards were considered as candidates for a future implementation. The comparison matrix presents obvious differences between the candidates shining light on possible strengths and weaknesses of each candidate, see figure 4.2. The comparison matrix is also presented in larger scale in Appendix M.

Benchmarking of Evaluation Methods		Ergonomic evaluation methods (Posture)											Organizations' standards			
		REBA	RULA	OWAS	EAWS	*NIOSH*	KIM I	KIM II	KIM III	HARM	RAMP II	JSI	SARA	VCS	GEELY	IPS
Neck:	Position	•	•						•	•	•		•	•		•
	Bend	•	•						•	•	•		•	•		•
	Forward head posture									•						
	Twist	•	•						•	•	•		•	•		•
Trunk:	Position	•	•	•	•		•	•	•		•		•	•		•
	Bend	•	•	•	•			•	•		•		•		•	•
	Twist	•	•	•	•	•	•	•	•		•			•	•	•
	Support				•										•	
Legs:	Bend	•		•	•		•	•								•
	Both feet	•	•	•									•			
	Feetdist (Inclines)							•			•			•	•	•
	Sitting			•	•				•					•	•	
	Squatting				•		•	•					•	•	•	•
	Kneeling			•	•		•	•					•	•	•	•
	Support				•				•							
	Walking			•	•				•						•	
Upper arm:	Position	•	•	•	•		•		•	•	•		•	•	•	•
	Abduction	•	•		•				•	•	•		•	•		•
	Raised shoulder	•	•							•						•
	Support	•	•		•					•						
Lower arm:	Extension	•	•		•				•	•	•			•	•	•
	Flexion	•	•		•				•	•	•			•	•	•
	Crossed arms		•													•
	Support								•							
	Out of side of body		•				•		•		•		•	•		•
Wrist:	Extension	•	•		•				•	•	•	•	•	•	•	•
	Flexion	•	•		•				•	•	•	•	•	•	•	•
	Radial deviation	•	•		•				•	•	•	•			•	•
	Ulnar deviation	•	•		•				•	•	•	•			•	•
	Supination	•	•		•				•	•						•
	Pronation	•	•		•				•	•						•
Hands	Coupling	•			•	•			•	•	•		•	•		
	Finger forces				•				•	•			•	•		
Muscle use:	Repetative	•	•		•	•	•	•	•	•	•	•	•	•	•	
	Exposure time				•	•	•	•	•	•	•	•	•		•	
	Rapid changes (Speed)	•						•			•	•				
Force/load:	Weight	•	•	•	•	•	•	•		•	•		•	•	•	
	Distance				•	•	•	•					•		•	
Rating method:	Rating based on table	•	•		•										•	
	Sum of groups						•	•	•	•	•	•	•			
	Index per group			•												
Point system:	1 -> 4 (G/Y/R/DR)	•	•								•	•		•		
	0 -> +50 (G/Y/R)				•		•	•	•	•			•			
	0-200														•	
	1 -> 7			•												
External factors:	Environmental (Temperature, tools, facility etc.)				•		•	•	•	•	•			•	•	
	Organizational (Work rotation etc.)				•		•	•	•	•	•		•	•	•	

Figure 4.2: Comparison matrix from the benchmarking study including the selected methods and standards and its assessments, own picture.

4.2.2 Complexity score

The complexity score of the identified candidates for implementation is visualized in figure 4.3. The graph visualizes two complexity scores per ergonomic assessment method or standard, the total criteria considered by the method or standard (1) and the number of criteria available for measure in IPS with the already existing ergonomic functionality (2), see figure 4.3.

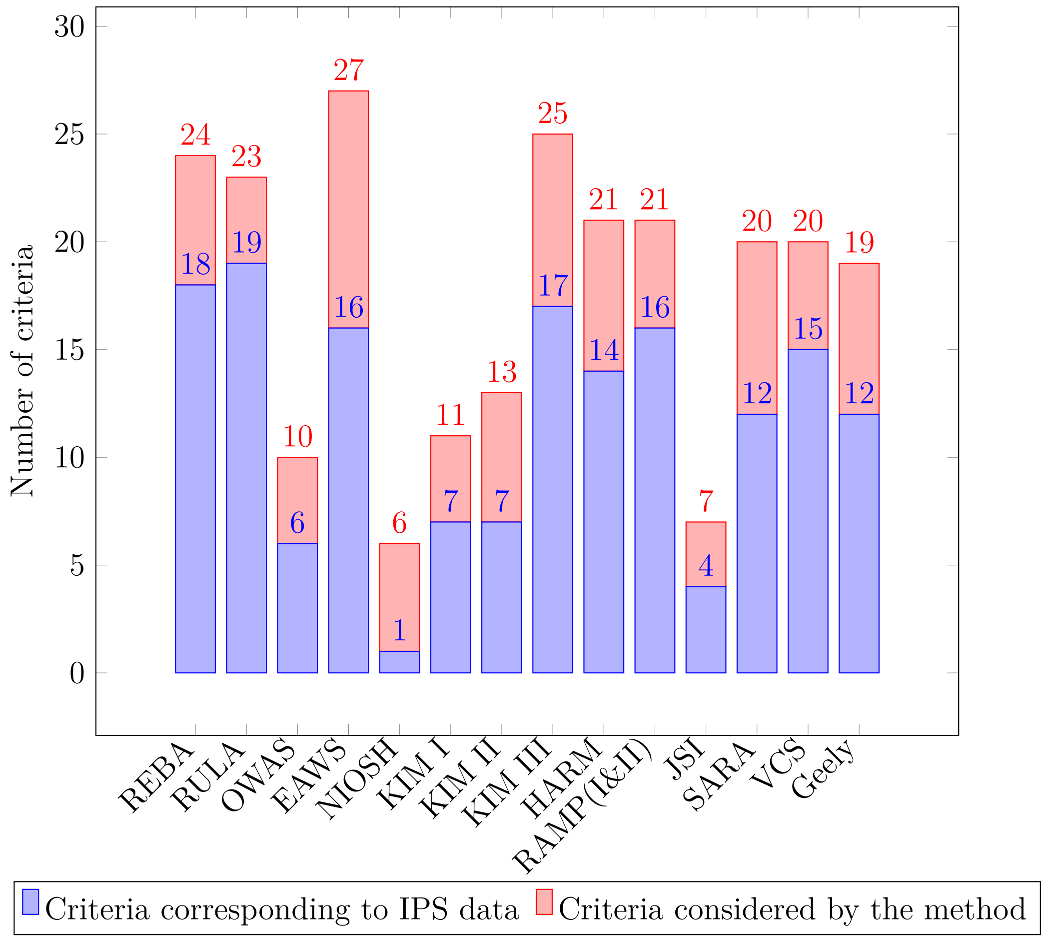


Figure 4.3: Quantitative data representing the complexity of each ergonomic assessment method and its implementation in IPS, own picture.

The result of the two complexity scores shows clear deviations between the assessment methods used in the benchmarking process when it comes to complexity. REBA, RULA, EAWS and KIM III all scored high in regard to complexity and the amount of criteria considered during the ergonomic evaluation. Meanwhile OWAS, NIOSH, KIM I, KIM II and JSI scored fairly low, making these methods less comprehensive and therefore subject for exclusion from further studies.

As RULA already has been implemented in IPS IMMA, the decision was taken at this point to exclude it from the benchmarking process. Supported by the interview and literature study that showed that EAWS was tightly connected to MTM time studies and dependent on an MTM-certificate [22], the decision was also taken to exclude this method from any future decision processes as well.

4.2.3 Kesselring matrix

The remaining methods were ranked according to their complexity scores and the top four methods were chosen as contestants in a Kesselring decision matrix, see figure 4.4. The included candidates were selected from the previous generated decision matrices, with the requirement of being a scientific-based method which is seen relevant to the industry. Thereby, SARA and VCS were excluded for further studies as they did not fulfil these qualifications.

Decision Matrix		Ergonomic Evaluation Methods							
		REBA		KIM III		RAMP (I & II)		HARM	
Criteria	Weight	Rating	Total	Rating	Total	Rating	Total	Rating	Total
Neck	3	3	9	4	12	4	12	4	12
Trunk	3	3	9	4	12	4	12	0	0
Legs	2	4	8	2	4	2	4	0	0
Upper arm	4	3	12	4	16	3	12	4	16
Lower arm	4	2	8	4	16	1	4	4	16
Wrist	5	3	15	4	20	3	15	4	20
Hands	5	2	10	2	10	4	20	3	15
Forces	4	2	8	4	16	4	16	3	12
Time	4	2	8	4	16	5	20	5	20
External factors	2	0	0	3	6	5	10	4	8
Clear scoring	3	4	12	5	15	4	12	5	15
IPS availabilty	4	4	16	3	12	3	12	3	12
	Total Score:		115		155		149		146

Figure 4.4: Kesselring decision matrix of the contested methods, modified by Leonard Bogojevic and Henrik Söderlund.

The criteria used in the decision matrix and their corresponding weights were decided by the project's performers after gathering a detailed view of what the ergonomic evaluation method should focus on. Thereby, relevant and reasonable decisions regarding such actions were made.

The Kesselring matrix showed that KIM III was the most suitable contestant for an implementation into IPS as it covered postures of the most risk prone areas of the body related to the relevant industry as well as took into consideration crucial time and force aspects. In addition, the KIM III input data and measurements have a clear correlation of those factors that are already available and retrievable in IPS, which makes a potential successful implementation more likely. Interview studies with industry experts also showed that KIM III is commonly used within the automotive industry, bringing a sense of familiarity to the users in a possible future implementation.

4.3 Results of implementation

The implementation resulted in an automatic generated KIM III report following the official KIM III template and structure. In the following section, the result of the implementation will be covered. The section will disclose the final results of the implementation as well as the workings of the functionality.

4.3.1 Choice of development strategy

In regard to the limitations in the already existing ergonomic functionality within IPS IMMA and its strong ties to RULA, the decision was taken to exclude the option of modifying the existing functionality through .JSON. It was instead decided to focus on a custom-built functionality adapted for the KIM III evaluation method using the IPS API and LUA-scripting in order to reach as good of a result as possible. Furthermore, due to the lack of visual possibilities and GUI within IPS, a fully integrated solution in IPS was also excluded in the development phase and a combination between IPS and a standalone reporting software was seen as preferred. Visual reporting was seen as an important aspect and deemed valuable by the project and its stakeholder in order to stay communicative and beneficial in a working environment. Finally, due to the limitations in time and program experience within the project team, the decision was taken not to develop any original software for the sole purpose of this project, but instead use an already existing third-party software available to the market providing relevant GUI and reporting capabilities. The software chosen suitable for the purpose of this project was Microsoft Excel.

4.3.2 Data structure of the functionality

The functionality uses the input on a certain set of questions from the user as well as algorithms of the IMMA manikins' posture to automatically generate a KIM III report. This is done in two steps. Simulation data is captured with the help of the IPS API and LUA-scripting of a custom function within IPS. The data is then processed and visualized in Microsoft Excel in order to create a standardized report. The transition between the two software is seamless and the report is generated by the single push of a button.

Scripting

The functionality in IPS has been developed using LUA programming language and the available API for IPS IMMA. The LUA-script creates a matrix of all the manikins belonging to a specific family identified in the IPS scene. The rotation in X, Y and Z of 19 selected joints of the IMMA manikins are then calculated using the IMMA API and added to the matrix categorized per each manikin in the family, see table 4.4. The rotational component of each joint allows us to calculate its angel thus making it comparable to most ergonomic assessment methods available.

Table 4.4: Table of representation of the matrix created by the LUA-script in IPS

	Manikin 1	**Manikin 2**	...	**Manikin n-1**	**Manikin n**
Joint 1	x y z	x y z	...	x y z	x y z
Joint 2	x y z	x y z	...	x y z	x y z
...	...	...	...	...	...
Joint n-1	x y z	x y z	...	x y z	x y z
Joint n	x y z	x y z	...	x y z	x y z

The 19 joints used in the current evaluation has been selected in regard to the postural aspects of KIM III as well as creating a holistic yet accurate representation of the manikin's full body posture, see figure 4.5 for a visualization of the joints captured by the script. The 12 joints in the figure are in practice 19, as some of the joints visualized in the figure are duplicated on the both sides (left and right) of the manikin.

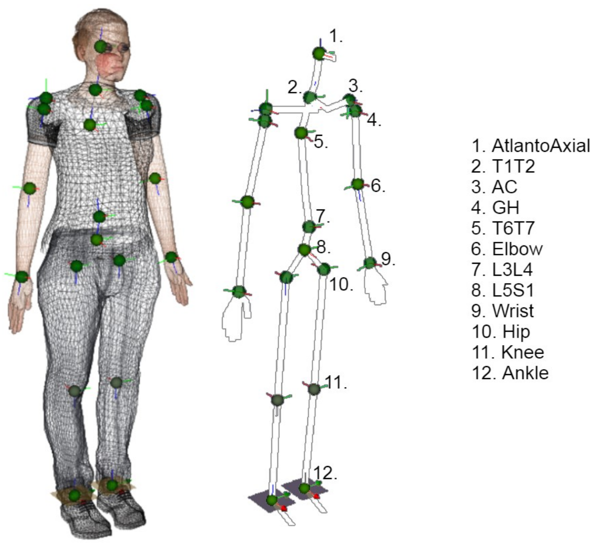


Figure 4.5: A visualisation of the joints positions and formulations considered by the script, own picture.

In addition to the rotational component of each joint, the matrix also provides an input of the seven questions posed to the user as well as miscellaneous data such as the name of the IPS-scene etc. used for the sake of the report.

Data transfer

Since IPS and its API lacks the possibility to create any kind of GUI or visual report, the decision was taken to export the data from IPS to a third-party software. In order to achieve this in as simple and universal way as possible an export of the data in a CSV-format, *Comma Separated Value*, was chosen. The LUA-script writes the matrix containing all the relevant data from IPS to a text file in a CSV format. The text file is stored locally or on a remote server, acting as a data carrier of the matrix created in IPS by the LUA-script.

When running the LUA-script, an execute command calls on a specific Excel-file to open on the user's desktop. Using a VBA, *Visual Basic for Applications*, macro, the text file containing the matrix in a CSV format is read, imported and formatted to an Excel-sheet.

Algorithms

Once the data was imported into Excel, it could be evaluated against a set ergonomic method and visualized in a standardized way. In order to evaluate the data exported from IPS, the rotational components of each joint needed to be translated into the angular constraints posed by KIM III. The constraints and angle of each joint was graded according to the guidelines developed by the German federal institute for occupational safety and health (BAuA), the founders of KIM III [28]. See figure 4.6 for an example of one of the KIM III postural grading conditions and the corresponding IMMA joint and its rotational component corresponding to the angle at question. A detailed list of all postural grading conditions posed by KIM III and its corresponding IMMA joints can be found in Appendix N.

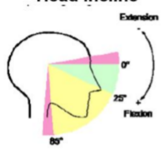
Illustration of Angle	Limits proposed by BAuA	Corresponding IMMA joints and rotational component
Head incline 	Green: 0° - 25° Yellow: 25° - 85° Red: >85° & <0°	AtlantoAxial.Y

Figure 4.6: An example of a KIM III grading constraint and its corresponding IMMA joint, own picture.

Following the mapping of each joint and rotational component, algorithms and calculations were conducted within the VBA macro to determine the grading and scoring of each angle following the guidelines and limits of KIM III. Minor modifications to each joint were made when necessary in order to adapt its rotation to the proposed limits according to KIM III.

4.3.3 Interaction with user

The structure of the final implemented solution could be divided into two steps, *Collecting data* and *Presenting data*. The first step gathers information that is required in order to fulfill the criteria of an actual KIM III evaluation. As the posture of the manikin is automatically collected from IPS IMMA by measuring its joints' positions and rotations, some data still needs to be gathered in order to complete a full KIM III analysis. This kind of data has been collected through a number of questions, which allows the user to manually select the answer which correlates best to the presented case. After these questions has been answered, the data is presented in the shape of a filled KIM III report.

Questions

Initially, as the user starts the function by pressing the "Ergonomic Assessment Button" in the upper toolbar, see figure 4.7, a pop-up window is presented to the user. This pop-up window presents a question to the user and requires an answer in order to proceed with the ergonomic evaluation. The answer to the question is given by selecting the most suitable answer from a dropdown-list below the question. The ergonomic evaluation function could at any time be annulled by pressing "*Cancel*" at the pop-out window. An example of the layout of the interface of a question is presented in figure 4.8.

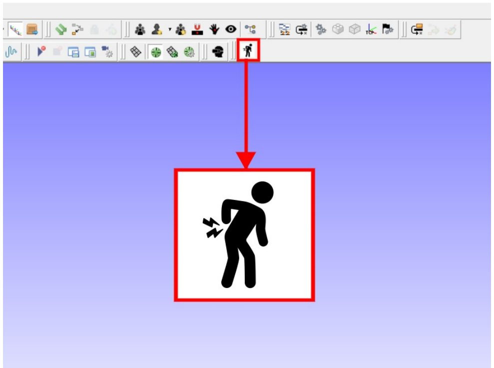


Figure 4.7: Ergonomic Assessment Button, marked in red, used to trigger the ergonomic function, modified screenshot from IPS.

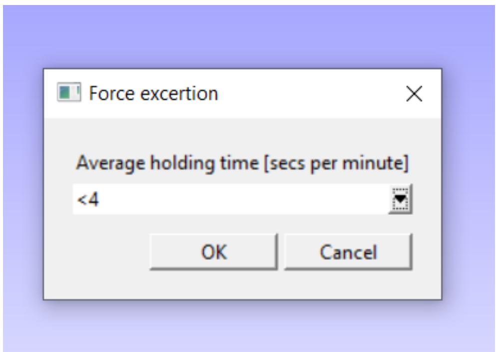


Figure 4.8: Illustration of a question's layout of the implementation in IPS, screenshot from IPS.

Another figure shows the same question used in figure 4.8 with its including drop-down tree displaying the different options of answers, see figure 4.9.

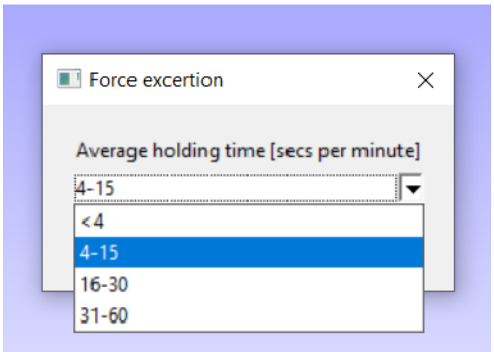


Figure 4.9: Illustration of a question's layout with its presenting answers of the implementation in IPS, screenshot from IPS.

A total of eight questions needs to be answered, in order to perform the ergonomic evaluation. These questions are presented below and could together with the available answers be found in the KIM III method [31].

1. Total duration of this activity per shift [up to ... hours]
2. What type of task is it?
3. Average movement frequencies [number per minute] / Average holding time [secs per minute]
4. What kind of force is exerted?
5. How good is the force transfer?
6. How often does variation in load situation occur?
7. How would you describe the working condition?
8. Which hand is used in the activity?

The formulated questions and answers that the user needs to select refers to the actual KIM III assessment, see Appendix G. Hence, the questions have not been made up or adjusted by the performers to be particularly suitable for this project. Instead, the questions have been gathered and transferred from the actual reporting sheet of a KIM III evaluation.

Reporting

Once all questions are answered, the system transfers the data from the questions together with the manikin positions to fill in a KIM III report in Microsoft Excel. Excel was selected to be used as a reporting tool because of its beneficial appearance and design opportunities, compared to IPS. Thus, the ergonomic evaluation report could - with the use of Excel - be designed in the shape of a KIM III assessment sheet.

The result is calculated based on two settings; the operator's answers on the questions and the posture of the manikin. With these two settings obtained, the results are presented in an Excel-sheet, displaying the KIM III report. As the KIM III method is calculated by adding a number of evaluation factors together [31], the same function has been implemented in the Excel report as well. By pressing a customized button in the sheet, displayed as "*Update Report*", see [a] in figure 4.10, the KIM III method's steps are filled in with the manikin measurements and the operator's selected answers. Thereafter, the report automatically gets filled in with values and colour boxes to enhance and visualize the results in an interactive way. This is presented in figure 4.11, which visualizes an example of the measured values of the wrist posture. Likewise, a screenshot of the case is also imported to the report along with the file name of the scene, to interactively visualize the results of the evaluation. The filled in answers and manikin measurements are used to calculate an overall assessment score according to the KIM III method. The report is illustrated in full and with relevant notes in Appendix H.

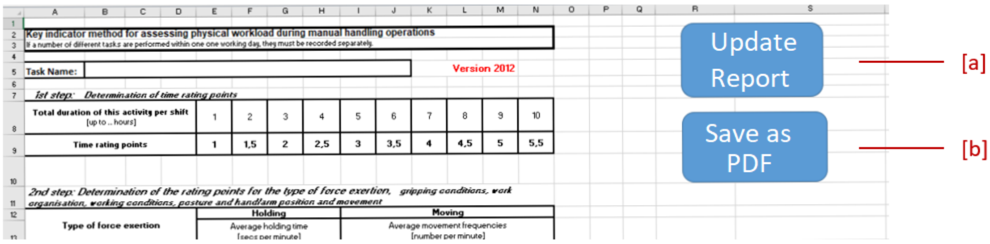


Figure 4.10: Snapshot of structure in Excel, with [a] presenting the customized button to update sheet with ergonomic information and [b] presenting the button to save the sheet in pdf.-format.

Hand/arm position and movement *)	Rating points
Good: position or movements of joints in the medium (relaxed) range / only rare deviations	0
Restricted: occasional positions of the joints at the limit of the 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
**) Typical positions are to be considered. Rare deviations can be ignored.*	

Figure 4.11: Reporting structure of hand/arm position and movement, where the red colour box represents an example of a resulted score, from printed PDF of the Excel sheet.

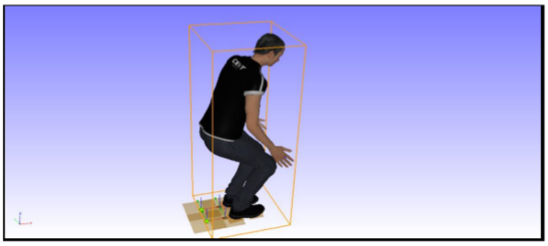
In the KIM III report sheet in Excel, there is also a function implemented to save the ergonomic evaluation to a pdf. file. This was implemented to simplify the ability to communicate the results, as a simple pdf. file seemingly would be easier to communicate than a complete Excel-file. The button for the save function is presented in figure 4.10 as [b] and saves a pdf of the report to the user's desktop with file name [KIM3_XXXXXXXX_XXXX], where XXXX represents current date and time.

The final assessment score is presented as a value from 0 to 50+, where the ergonomic assessment gets worse as the total score rises. A total of four limits are given and reached in the KIM III method depending on the final score. In the method, the range of score correlates to the following outputs [31]:

- < 10 - *Low load situation*
- 10 to < 25 - *Reasonable risk*
- 25 to < 50 - *High risk*
- > 50 - *Very high risk*

In the implemented report, the limit which the result of the evaluation represents gets highlighted by a surrounding box. The colour of the box is green, yellow or red depending on the final score, see figure 4.12.

	Type of force exertion(s) in the finger- hand range	0
+	Force transfer / Gripping conditions	0
+	Hand / arm position and movement	2
+	Work organisation	0
+	Working conditions	0
+	Posture	3
=	Total	5



x Time rating points 1 = Risk score 5

Risk range ***)	Risk score	Description
1	<10	Low load situation, health risk from physical overload is unlikely to appear.
2	10 to <25	Moderate load situation, physical overload is possible for less resilient persons. For this group redesign of workplace is helpful.
3	25 to <50	Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.
4	>50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.

Figure 4.12: Display from the report presenting exemplified results of a KIM III ergonomic assessment.

Moreover, an additional functionality to the reporting format has been added, allowing the operator to see the assessment score of all of the manikins inside the evaluated family. Thereof, the sheet could be updated with another manikin's values, from the same family, by marking that specific manikin and thereafter pressing the customized button "*Select New Manikin*". This is visualized and presented in figure 4.13, see [c].

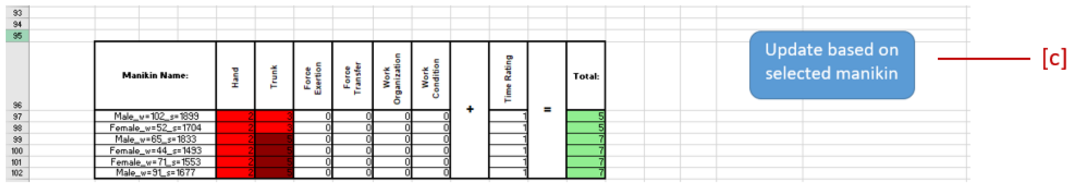


Figure 4.13: Snapshot of structure in Excel, with [c] presenting the customized button to update sheet with new manikin.

4.4 Verification and validation

The **verification** of the project was carried out by ensuring that the programming code of the function's scripts were accurate and true. By investigating and constantly using the debugger to check the code, errors and mistakes could be found and corrected early on in the process. Moreover, the code and function were presented to supervisors, colleagues, and other stakeholders to ensure that the coding was done in a correct and appropriate way. Another part of the verification stage was to let all of the daily users of IPS IMMA at CEVT try out the function and explore it for themselves. This allowed for feedback and the users got to share their general impression and opinions regarding the functions accuracy, user-friendliness, etc. With that, some smaller bugs in the code could be located and corrected for the *final* version of the function.

Initially in the **validation** phase, CEVT's ergonomic expert Agneta Figaro presented a few previous cases of hers that could be used to validate the function. By setting up a scene in IPS based on the parameters provided by Figaro, a digital ergonomic assessment could be done and compared to Figaro's physical assessment. It was also confirmed with Figaro before making the evaluation, that the scenes created in IPS corresponded with Figaro's impression of how the scene was designed. Once this had been done, the two ergonomic assessments (the manual and digital KIM III methods) could be compared to one another. From the completed cases, it could be seen that the digital assessment correlated well with the physical assessment performed by CEVT's ergonomic expert.

A representative manikin based on default manikin representing an average of the workforce was selected and used in the validation cases described below.

4.4.1 Validation case 1

The first performed case study concerned the manual assembly of the sunroof into one of the cars developed at CEVT. The assembly task is performed by tightening roof mounted bolts using an electrical power tool. The placement of the bolts lead to work above shoulder height with rather high loads and awkward body posture, which the ergonomist at CEVT mentioned was seen as one of the worst cases she was ever assigned. A describing snapshot of the manikin performing the assembly task is presented in figure 4.14.

Figure 4.14: Digital illustration of how the assembly of the sunroof was performed, from IPS.

The results of the manual KIM III evaluation performed by Figaro can be seen to the left in figure 4.15, whilst the results of the digital KIM III evaluation can be seen to the right in the same figure.

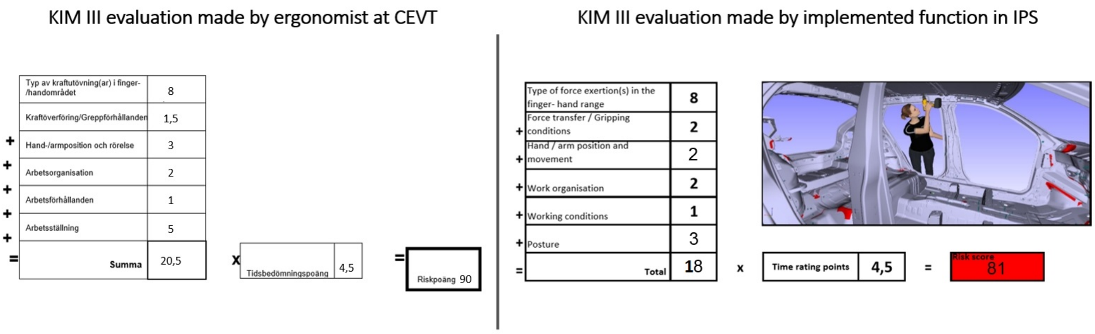


Figure 4.15: Validation case 1 results of KIM III assessment done by ergonomist at CEVT (left) and through implemented function in IPS (right), screenshot from KIM III digital assessment.

As can be seen in figure 4.15, the two results from the methods correspond well with final scores of 90 and 81. It is also evident that scores for the posture and hand/arm position and movement - which are measured by the function - were scored different, with a value of 3 and 2 in the digital assessment and 5 and 3 in the manual. In both assessments, the result was given the highest risk factor, implying that change is required.

Furthermore, two more validation cases were conducted in order to obtain credibility of the function and make sure that it correlated well with the physical assessment made by the ergonomist at the company. The additional validation cases had various results and all matched the digital KIM III evaluation well.

4.4.2 Validation case 2

The second case regarded an assembly process of a part into a wheelhouse of one of the cars developed at CEVT. The assembly task required a lot of work with blocked visibility, causing the operator to either bend his/her head in an uncomfortable position to see where to mount the part, or to fully perform the operation based on intuition. A describing snapshot of the manikin performing the assembly task is presented in figure 4.16, where the manikin represents the operator performing the tasks on intuition without making an uncomfortable tilt of its head.

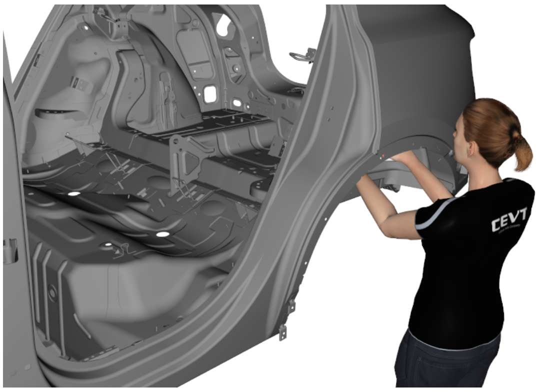


Figure 4.16: Digital illustration of how the assembly of a part into a wheelhouse was performed, from IPS.

The results from the two performed evaluations are presented below, with the ergonomist's manual assessment to the left and the simulation's digital assessment to the right in figure 4.17.

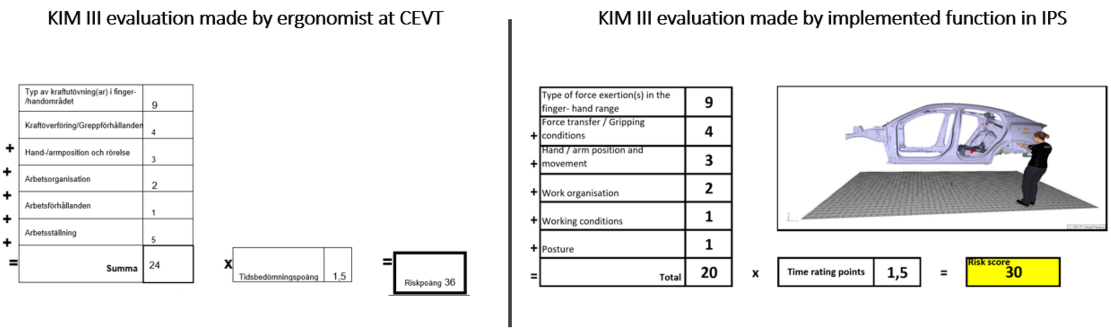


Figure 4.17: Validation case 2 results of KIM III assessment done by ergonomist at CEVT (left) and through implemented function in IPS (right), screenshot from KIM III digital assessment.

From the results presented in figure 4.17, it can be identified that the final scores differ with 6 points between the manual and the digital assessment. If the assignments are investigated closer, it can be seen that the difference originates from the posture analysis, where the manual assessment has given the score of 5 whilst the digital assessment has assigned the posture factor with the score of 1. Arguably, the reason for this variation is because the manual assessment included the operator making an uncomfortable bend in order to gain visibility of the part. This would call for the manikin to bend down with its upper body and tilt its head under the wheelhouse to see the mounting position. The KIM III method does not consider the visibility of the operator, thus nor does it evaluate whether the manikin can see an object or not. The IPS software does neither take the field of view of the manikin into consideration when posing the manikin. The two assessments do however represent the same risk score, with the risk range between 25 to < 50, implying that redesign of workplace should be reviewed.

4.4.3 Validation case 3

The third validation case performed together with the ergonomist at CEVT, was of an assembly task of a clip used in the fuel line assembly in one of the car models developed by CEVT. The fuel tank and its subsystems are assembled onto the chassis while it travels on a raised pallet before being merged together with the car body. The pallet allows for a somewhat decent working height and reach of parts which otherwise would have been inaccessible to the operator due to its placement underneath the car body. The fuel line is attached to the chassis by clips and assembled by applying manual force and pressure. A describing snapshot of the manikin performing the assembly task is presented in figure 4.18.

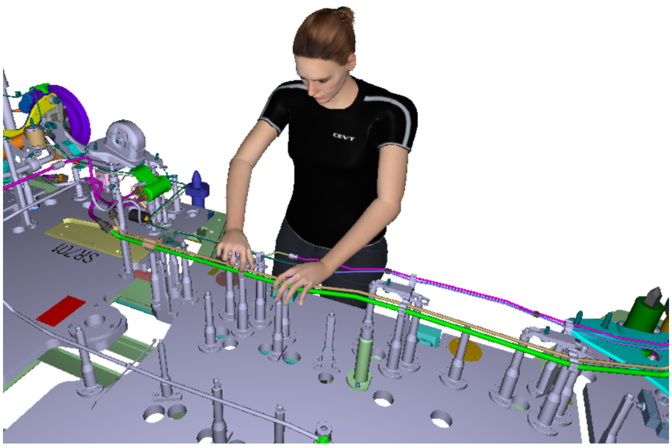


Figure 4.18: Digital illustration of how the assembly of the fuel line clip was performed, from IPS.

A comparison of the evaluations is presented below, with the ergonomist's manual assessment to the left and the simulation's digital assessment to the right in figure 4.19.

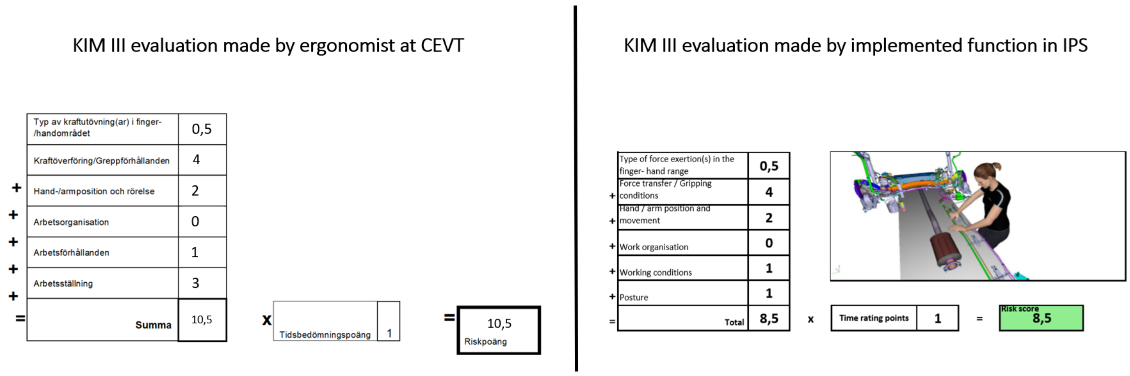


Figure 4.19: Validation case 3 results of KIM III assessment done by ergonomist at CEVT (left) and through implemented function in IPS (right), screenshot from KIM III digital assessment.

As can be seen in figure 4.19 the results of the two evaluations correlates quite well with each other. They both achieve a green score with the discrepancy of 2 points. This due to the different scores on the postural factor of the evaluation, where the ergonomist at CEVT graded the postural risk as a 3 while the implemented function in IPS graded the risk as a 1. However, both evaluations still indicate that no redesign of the station is necessary at this point, as they both result in the low risk ranges.

4.4.4 User testing and feedback

As a part of both the verification and validation process, an initial version of the function was handed out to the users of IPS at the ME department at CEVT. The initial version of the function acted as a beta version, were the users got to test and explore the function and then bringing feedback on how it could be improved. The feedback would in that way bring value to both the verification as well as the validation of the project. The feedback presented by the users included allocation of bugs, improvement proposals and general impressions. Relevant feedback that was obtained concerned i.a. report layout, formulation of questions needed to be more specified and the option to include multiple manikin families was suggested. The feedback was digested and analysed by the project group and revised in an iterative process with the structure similar to the PDCA-cycle [54]. Consequently, all feedback provided from the users of the test-run was analysed, and improvements were made accordingly.

Moreover, it was also brought to the author's attention that concerns rose regarding insufficient insight and knowledge regarding the line balancing and factory environment by the ME employees in order to answer the posed questions in an accurate way. This led to that an additional document being made, consisting of examples and guidelines on how to answer each question, see Appendix O.

5 Discussion

The results of the developed methodology aimed to give an answer to the presented research question regarding how ergonomic assessment of assembly work could be automated with the use of IMMA in IPS. The problem identifications of the project were successfully answered, but also entailed a few points which opens for discussions. This chapter will go through the noteworthy findings of the project and discuss them reasonably and justly. Relevant subheadings have been structured to outline the methodology, evaluation method, digital function as well as experiences for future work.

5.1 Methodology

The developed methodology entailed working in a structured and determined way to finally reach a result to the presented research question. The methodology included e.g. brainstorming processes, data gatherings, studies of learning a new programming language and managing a new simulation software. As it is safe to say that these processes required a fair proportion of time in order to be done right, it should also be addressed that it is important to make delimitations in order to not spend too much time on non-value adding tasks. By working in parallel with constant communications, the group could reach an effective work method and reach results at early stages. Another factor that should be mentioned is also that by structuring the work tasks, the group could avoid potential issues causing delays and inefficiencies to the project. This was for instance when the group decided to interview all of the stakeholders of interest at early stages of the project, allowing for further and more elaborate research and analysis of the interviews.

Due to the current situation with the COVID-19 virus pandemic, it was ordered that all employees of CEVT should work from home from week 10 to the final week of the project. This only allowed for digital meetings and dialogues with stakeholders, eventually causing some delays in receiving response. This resulted in the validation process to take up for more time than planned for, as the communications to stakeholders via e-mails usually required a couple of days to respond. From that point of view, one could say that it was beneficial that the group had made all interviews and data collection before home-quarantine was established. The restricted access to the office during this period also resulted in limited access to CEVT's VR, *Virtual Reality*, -lab and its virtual reality equipment. Equipment planned to be used in the continuation of the project to assess the impacts and benefits virtual reality could have brought to a virtual ergonomic assessment.

The methods to conduct certain tasks in the project were decided based on either suggestions from supervisors or relevant assumptions from the project group. The group could take advantage of reusing applicable methods learnt from studies at the university. This did for instance result in the use of the different matrices in the benchmarking process, which eventually resulted in a final ergonomic evaluation method to implement. It could thus be interesting to see how the methods would have scored with the use of different processes, if other decision matrices would have been used, apart from e.g. Kesselring. The scoring and weighting in the Kesselring matrix were also subjectively decided, which could result in that a different score would have been given if another person would have conducted the screening. Although, the authors saw the advantage of including input from an ergonomist, and thereby involved CEVT's ergonomist in the process and decided the scores and weights in consensus. The decision was also made based on statistics and data of e.g. common injuries, in order to result in the most relevant scoring and weighting points.

5.2 Evaluation method

From the methodology of the project, KIM III was decided to be the most suitable method to implement out of the benchmarked methods. As these methods only represents a fraction of all of the potential ergonomic assessments used worldwide, one could argue that the results could have been different if other assessments had been used. It is however unclear what the results would have been in that situation, and any logical assumptions regarding the question are difficult to make. What could be said however, is that the KIM III ergonomic method was suitable to implement to IPS for numerous reasons. Not only did the method score the highest in the benchmarking process, it is also a method that is commonly used by the ergonomist at CEVT today. This made the method particular interesting since it would be recognizable by some of the employees at the ME department at CEVT as well. This would result in that a portion of the people working with it would not have been obligated to learn and acknowledge a new ergonomic assessment method, as they would already be familiar with the KIM III method. However, in order to perform a KIM III evaluation method, the operator needs to have some background information in how the assessment is structured. To help with this, a document providing background information and guidelines of how to use the digital ergonomic function was developed and handed out along with the implemented function. Reading this short guideline document would provide enough information to perform a successful and correct KIM III evaluation method in IPS. The complete guideline is visualized in Appendix O.

Even though KIM III was seen as the most suitable method to implement, it was not designed to be fully automated in IPS as it, as well as all the benchmarked ergonomic assessment methods, is based on observational methods. Since it for various reasons was not fully automated, a few questions to the user had to be formulated in order to get all required information necessary to perform a KIM III evaluation. As a result of this, the complexity of the method increased. There is however, to the authors knowledge, yet no ergonomic evaluation that could be fully automated, as some information cannot at this moment be simulated in a proficient way (e.g. temperature, vibrations, etc.). For that, the DHM-software needs to be further developed and improved. However, the interest to develop an ergonomic assessment more applicable to digital tools and simulations would also therefore be of great interest, but does not get covered in this thesis.

5.3 Digital function

The KIM III ergonomic function in IPS was successfully implemented, verified and validated before the final weeks of the project. When conducting the function, it was important to consider accuracy, layout and user-friendliness, in order to obtain a valuable tool for the CEVT employees. How the function was designed and built was to most users thereby less relevant, as they would only interact with the output of the function. The decision to develop the function through LUA-scripting was for the same reason only made to improve the parameters of importance to the users.

Prior to the thesis, none of the group members had encountered IPS or LUA as a scripting language before. Still, they were both easy to learn and easy to understand the fundamentals, which the function is based on. IPS as a software was seen really useful if it could be used correctly. The possibilities of making additional functions and tools to the program made it easy to understand the great potentials of the simulation software. Great potential with the IMMA function was also identified. The function allowed for predominant simulations and analyses, but could sometimes provide the impression of needing further development. Further programming through VBA in Excel was also completed. The authors did however have some previous experience of other programming languages (i.a. VBA), which was helpful in the implementation of the KIM III evaluation method.

It is evident that the users completing the KIM III function needs to have consisting knowledge in IMMA and the IPS software. Not only do the users have to know how to perform an evaluation in IPS, they also need to know how to manipulate the manikins in order to find the correct position. This has been shown to be a bit trickier than one would think in some cases. First, the users need to know how the manikin should be positioned in order to get an accurate evaluation. The manikin does in return need to be smart enough to be able to find and anticipate the position and posture that an operator would adapt in a real-world scenario. This was however sometimes shown challenging. Unless the IPS user or the software is able to predict a correct and accurate posture, the ergonomic assessment might be compromised. In this regard it would have be interesting to study how the result of the KIM III assessment would differ when performed by experienced simulation engineers at CEVT in comparison to the authors.

It was also shown vital that the user has access to correct data and information about the factory, its manufacturing strategy and the assembly operation in order to make the correct assumptions when answering the additional input questions to the KIM III assessment. But with a correct use of the tool and good insight in the factory and assembly process, the authors definitely think that time will tell that it is a powerful tool for ergonomic evaluations.

5.4 Validation cases

The verification and validation stage was seen by the authors as an essential part of the project in order to create value and bring significance to the product. The implementation was thereby validated through multiple cases and an extensive test run. These two methods were considered as two main inputs in the validation stage. The validation cases were completed by comparing the ergonomist's assessments to the digital assessments made with the implemented function in IPS. The results were considered as beneficial and promising in terms of creating a legitimized function that corroborate well with the real-time ergonomic assessments made by the ergonomist at CEVT today.

From the validation cases, it was seen that the results could have some differences in final score, but did end up having the same risk range. In the three performed cases the digital assessments did result in a small underrating in comparison to their manual assessments. This is the consequence of a smaller deviation in the postural factors (hand/arm position, movement and posture). In the three cases, the posture factor was by the KIM III function in IPS scored lower than the ergonomist at CEVT. Making decisions with the ergonomist's evaluation as a reference, this could either imply that the function needs to be further validated, that there has been deviations in the input data or that there is discrepancy between the observational assumptions made by the ergonomist and the actual joint angels in the manikins. Since all the cases have been performed by recreating already performed assessments, the exact data regarding how the operator was positioned and etc., was incomplete. Instead, the ergonomist together with other employees at the ME department at CEVT have provided their best insights in how the task was conducted, based on their experiences. Furthermore, data regarding the observed operator's height and anthropometry was insufficient, hence a manikin with average dimensions was used in the validation cases. This could be the ultimate factor for why there has been deviation in the evaluations of the postural factors.

It can also be seen that when comparing the different assessments as done in the validation, the posture score can vary - without having a significant impact on the final score. Hence, by solely looking at the final score of an assessment, a task could still be confirmed with an existing ergonomic risk of the posture of the operator. Since the KIM III assessment method puts a large weight on questions regarding organisation and conditions etc., it can create a complication if the issuer of the simulation does not possess that particular input. Moreover, with the digital simulations being developed as of today, together with the fact that people at different departments does not always hold information about all the things asked for in the KIM III method - one might suggest that it would be better to consider solely postural assessments for an ergonomic evaluation. The purpose has in this project however been to implement a complete ergonomic evaluation method, which in turn required the use of questions to obtain information needed to fulfil the criteria of performing the full method.

5.5 Experience for future work

From the results of the project, an ergonomic assessment of assembly work could be automated (to some extent) using IMMA in a virtual simulation system. The implemented function could drastically reduce time to perform ergonomic evaluation - leveraging performance and generating economic value in the process and product development as well as the production technology at CEVT. By resulting in less work-related MSDs and better product quality, less expenses would need to be allocated and the safety would increase, which correlates to bringing economic value.

It should however be mentioned that it is strongly recommended that the ergonomic simulation function does not fully replace manual real-time assessments. The tool does with the current design only bring a holistic perspective of a certain task, but does not in any way need to be fully representative of an actual station. The tool should be used as a "first impression"-basis to strengthen or weaken already existing ideas of ergonomic values.

Moreover, developing new methods that are more suitable for digital ergonomic evaluations would be of great interest. Many of the ergonomic assessment methods used today in the industry are not developed with simulations in mind and should thereby be further investigated. This would help the simulations to be more accurate, representative and user-friendly. It would also potentially result in higher degree of automation, where the users would not be required to answer any questions. Another way around the issue of questions in IPS would be to develop the DHM-software to manage new types of data and information, including the factors which are difficult to simulate with today's DHM-software.

To further increase the value of the KIM III ergonomic function, the authors propose future development of analytic functionalities. Examples of such functionalities could include deeper analyzes of the output data, presenting more detailed information about certain results. Such information could for instance concern what specific joint or motion has the biggest impact on a certain posture score or highlighting potential areas of risks. It could also be investigated whether a comparison of the posture score in each category towards the evaluation limits could increase the analytic value and user-friendliness of the function.

6
Conclusion

This master's thesis has provided a tool for digital ergonomic simulations of the KIM III method through the DHM software IPS IMMA. The methodology used for developing the function followed four major steps. The first step being multiple types of data collection, the second step containing the benchmarking and mapping phase, third step being the implementation stage and the final step consisting of verification and validation of the results.

From the results, the conclusion could be drawn that the implemented function correlated well with the manual ergonomic assessments made by the ergonomist at CEVT. The thesis does thereby show that an ergonomic assessment could be done digitally with the use of IPS and IMMA, saving a lot of time spent on making manual assessments. Hence, the application could eventually improve anthropocentric ergonomics, leverage performance and generate economic value in process development, product development and production technology.

Furthermore, the following conclusions regarding the application may be drawn:

1. The tool can be used to make digital ergonomic assessments of the KIM III method through IPS and IMMA.
2. The digital assessment can to some extent automate ergonomic evaluations, but should at this point not fully replace physical evaluations.
3. The user needs to have some consisting knowledge in IPS, ergonomics and manufacturing in order to make a justified evaluation.
4. The evaluation is dependent on the manikin's posture, measuring its joint positions and rotations. It is thereby essential that the manikin represents the actual operation to make a truthful assessment.
5. KIM III, as well as all covered ergonomic assessment methods in this project, is observational based, meaning that a fully automated solution was difficult to achieve and additional input is still needed by the user.

Answering the proposed research question, this project has shown that ergonomic assessments of assembly work can be automated using the DHM software IPS IMMA. This can be achieved by implementing appropriate ergonomic assessment methods, acquiring the essential information and data needed to complete the assessment as well as setting up an accurate and representative scenario within the simulation software. Furthermore, the five initial problem identifications have been reviewed continuously throughout the report and over the course of this project.

7
Future Work

Although ergonomic assessment, to some extent, might be available through DHM-software, they are not commonly used in the industry today. But it is an emerging market. The principle is simple, avoid risks related to ergonomics by identifying them even before the workstation is designed. But in order to do so in a sustainable way, a few criteria need to be further investigated, developed and met. The authors therefore emphasize that future research should firstly be conducted regarding; Motion/Posture simulation, Ergonomic assessment method for simulations and Data management.

7.1 Motion/Posture simulation

Being able to anticipate and simulate the correct kind of motions and postures is vital in order to achieve an accurate and representative ergonomic assessment. There are often a multiple different ways of how to perform a task and consequentially just as many different postures that could be adapted. Hence, one of the biggest challenges as a user of any DHM-software at this point is to anticipate the correct posture that would represent the reality of the situation [57]. The authors see two possible areas of future research that would address this issue and assist in anticipating the correct posture.

The IMMA manikin with its comfort-function and intelligent kinematics model is one of the most advanced manikins available when it comes to anticipating postures and movements according to assigned tasks. However, the results of this project show that even more research needs to be conducted regarding the comfort-function and movements of the manikin. For instance, as shown in the validation case 2, the IMMA manikin neglects any hindrance of visibility when posing itself. Meaning that it does not consider that the task to perform or object to assemble etc. is covered by the manikin's field of view. The IMMA manikin needs to be further developed to anticipate more accurate motions and postures in order to achieve correct and automated ergonomic assessments.

7.1.1 VR and Motion Capture solutions

An additional proposed area of future research that could help in achieving accurate motions and postures of IMMA, is the use of VR and motion capture. VR allows the users and operators to perform assembly tasks in a virtual environment early on in the design phase. Thus, creating a better feeling of how the task could be performed in a realistic way [58]. In combination with a motion capture system, the motions performed in the virtual reality simulation could be captured and transferred into the DHM-software bringing realistic motions to its manikins [59].

Throughout the project, the authors have had the opportunity to perform the three validation cases presented in chapter 4 - *Results*, using a virtual reality plugin for IPS. In the VR-scenarios evaluated by the project the manikin's hands were attached to the controllers of the VR-equipment, leading to the manikin mimicking the VR-users posture based on inverse kinematics from its hands. The VR-tool was proven useful and powerful in order to create a quick and credible feeling of how the assembly would be tackled by an operator thus leading to realistic postures and motions of IMMA. The validation cases run in the virtual reality setting achieved the exact same result as the validations performed on a desktop computer, indicating its potential. It was also discussed during these VR sessions, how the physical feedback through the use of physical objects to represent e.g. a car's body, could be used to enhance the experience of the VR user. It would seemingly be important to position the physical objects at the exact position of the digital objects, or the virtual experience would be less immersive and useful.

The potential of using Motion Capture systems in combination with VR to keep track of the manikin's position and rotation was also discussed during the development of the project. By using such a system to mimic a real person's movement and transfer that data to the digital manikin, one could argue that the time and effort of manually positioning a manikin could be reduced while the accuracy of its motions increases. A solution that was brought to the authors' attention was the *"Xsens"* 3D motion capture technology, that was showcased during a live session with researchers from Skövde University. The technology is based on a WIFI and magnetic field solution, to identify and define positions of a number of sensors placed on a real person's body. A demonstration by the researchers at Skövde University showed that the solution was compatible with IPS IMMA, where the positions of the real person could be transferred and mimicked by IMMA.

7.2 Ergonomic assessment method for simulations

In today's constantly changing and developing digital society, it is essential to change with it to avoid perishing. Arguably, this concerns ergonomic assessments as well. Since more and more ergonomic assessments are aimed to be performed at early stages to prevent MSDs, simulations have shown to be a useful tool to do so [60]. However, in order to perform a complete ergonomic assessment method or standard, there is a high requirement of having information and data of the process. Not only does most ergonomic assessments entail posture and observatory judgements, but also lots of objective assessments regarding i.a. underlying process information such as e.g. work environment, work rotations and noise. This type of data could be a bit more difficult to simulate and does thus put a higher demand on data management. Making subjective estimations of objective data could result in untrustworthy results of the ergonomic evaluation. Further investigations on how to manage such data should thereby be completed.

Subjective assessments have shown to have the potential to either benefit but also to harm an evaluation conduction. For instance, making evaluations of force transfer in the KIM III method does not concern the gradient of the force, rather than how the force was transferred. Meaning, does the force action result in the operator pressing an object or does the operator need to hit it? These types of judgements could be assessed differently depending on who's making the assessment. It should thereby be investigated whether or not the ergonomic assessment would benefit if the subjective assessments were to be neglected and an objective ergonomic evaluation was obtained.

Further work should include investigation in what ergonomic assessment methods or standards would be most suitable to implement into a simulation. Are there any methods that seemingly would be a better fit to implement than the KIM III method implemented in this project? Or would it be beneficial to implement solely postural judgements? Another interesting factor would be to consider the possibilities of developing a new ergonomic method or standard related to simulations. Since most assessments were developed before the use of ergonomic simulations were established, one could argue that they are not designed to correlate well with simulations. From that perspective, an ergonomic assessment method that has been created with concerns to be used in simulation purposes would be of great interest and would also be ground-breaking in this particular subject.

7.3 Data management

As shown in this project, ergonomic assessments are much more than pure postural judgements. The combination of time, force, posture and environmental aspects all needs to be considered in order to achieve a trustworthy and holistic assessment of the operators harms and risks. Also shown in this project are the difficulties of accessing and simulating such data in an automated manner. Hence additional input from the user is to a large extent still needed. This calls for great insight and knowledge by the user as well as availability of information and data. Insufficient or inaccurate data will in turn have a negative effect on the credibility and quality of the ergonomic assessment. Therefore, data and knowledge management are of great significance and should be considered for future work.

One area of interest proposed by the authors to increase the availability and quality of data is the area of digital twins. Digital twins of the factory or assembly station could act as data carriers of vital information and input to an ergonomic functionality [61]. It has the potential to carry all data necessary to address the relations between force, time, posture and environmental factors. Example of such data are as follows; weights, dimensions and properties of tools and parts, station layouts, lightning conditions, cycle times and exposure times. Having access to this kind of data would allow for a more accurate ergonomic assessments, performed by personnel with little or no insight in the real production. Digital twins or similar data sharing platforms could in many cases be seen as a prerequisite for ergonomic simulations. None the least for CEVT who is working remote, designing cars and platforms without any physical connection to any of its producing facilities.

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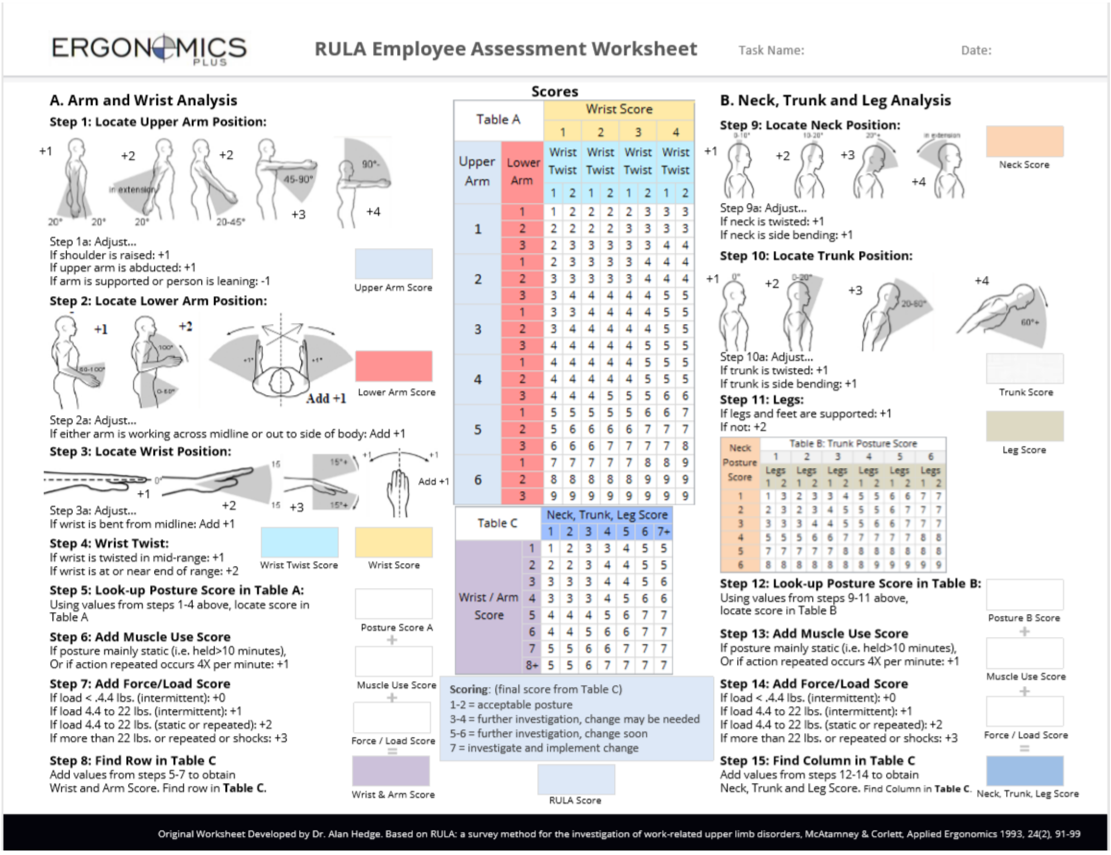
Appendices

A

Appendix - RULA



ERGONOMICS PLUS

RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

+1 +2 +2 +3 +4

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:

+1 +2 Add +1

Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

+1 +2 +3 Add +1

Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Wrist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 7: Add Force/Load Score
If load < .4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain
Wrist and Arm Score. Find row in **Table C.**

Wrist & Arm Score

Scores

Table A		Wrist Score 1		2		3		4	
		Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
Upper Arm	Lower Arm	1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C		Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
Wrist / Arm Score	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5
	3	3	3	3	4	4	5	6
	4	3	3	3	4	5	6	6
	5	4	4	4	5	6	7	7
	6	4	4	5	6	6	7	7
	7	5	5	6	6	7	7	7
	8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1-2 = acceptable posture
3-4 = further investigation, change may be needed
5-6 = further investigation, change soon
7 = investigate and implement change

RULA Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

+1 +2 +3 +4

Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:

+1 +2 +3 +4

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Neck Posture Score	Table B: Trunk Posture Score 1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above,
locate score in Table B

Posture B Score

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 14: Add Force/Load Score
If load < .4.4 lbs. (intermittent): +0
If load 4.4 to 22 lbs. (intermittent): +1
If load 4.4 to 22 lbs. (static or repeated): +2
If more than 22 lbs. or repeated or shocks: +3

Force / Load Score

=

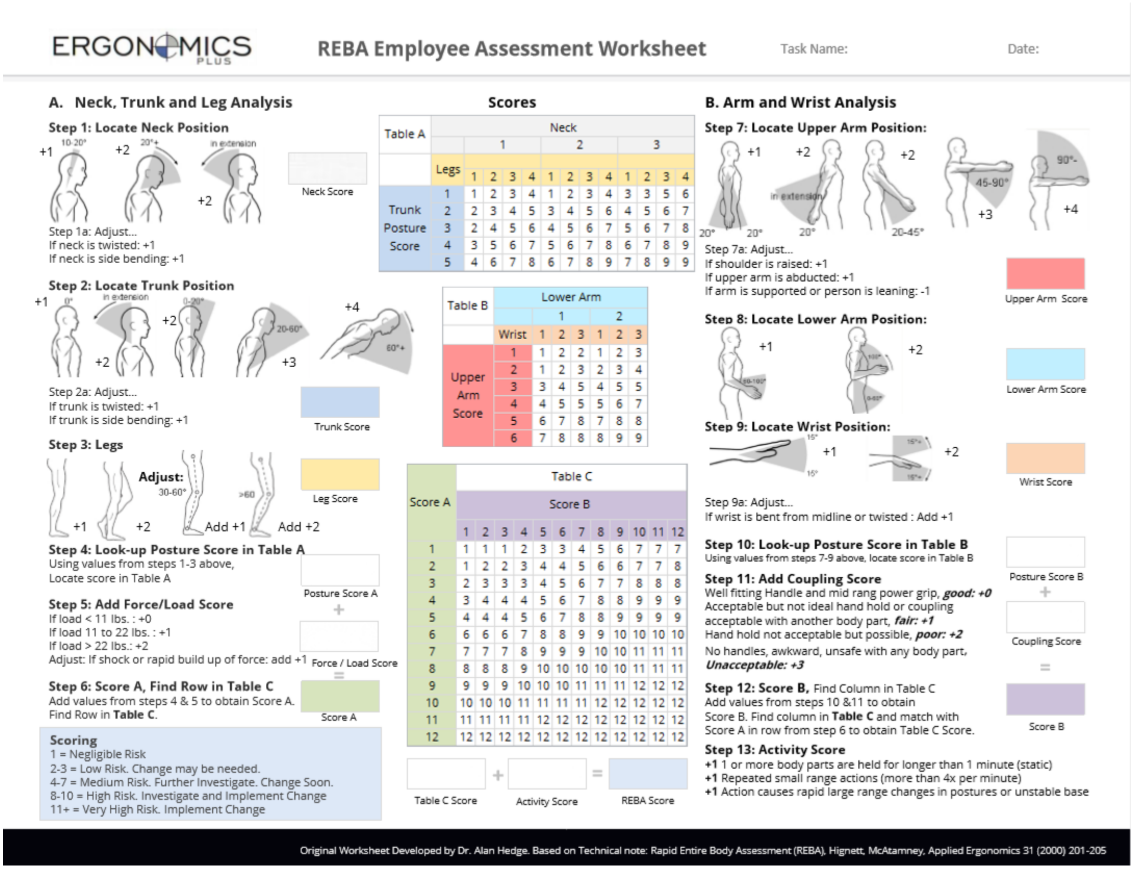
Step 15: Find Column in Table C
Add values from steps 12-14 to obtain
Neck, Trunk and Leg Score. Find Column in **Table C.**

Neck, Trunk, Leg Score

Original Worksheet Developed by Dr. Alan Hedge. Based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

B

Appendix - REBA



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name:

Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ +2 in extension

Neck Score

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° +2 in extension +2 0-20° +3 20-60° +4 60°+

Trunk Score

Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs

+1 +2 **Adjust:** 30-60° Add +1 >60 Add +2

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20° 20° +2 in extension 20° +2 20-45° +3 45-90° +4 90°+

Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

+1 60-100° +2 100°+ 0-60°

Lower Arm Score

Step 9: Locate Wrist Position:

+1 15° 15° +2 15°+ 15°+

Wrist Score

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling
acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part,
Unacceptable: +3

Coupling Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

C

Appendix - OWAS

BACK	ARMS	LEGS	LOAD
1 Straight	1 Both below shoulder	1 Sitting	1 < 10 kg
2 Bent	2 One above shoulder	2 Standing on two legs	2 < 20 kg
3 Twisted	3 Both above shoulder	3 Standing on one leg	3 > 20 kg
4 Bent and Twisted		4 Standing on two bent knees	
		5 Standing on one bent knee	
		6 Kneeling	
		7 Walking	

OWAS

The observation is expressed in 5 number code (*****), where the first number means the posture of back (1-4 points), second number the posture of arms (1-3 points), third number the posture of legs (1-7 points) fourth number the load (or use of force, 1-3 points) and a fifth number represents the work phase analysed if the task is analysed in a sequence.

Back	Arms	Legs	Load	
				1
				2
				3
				4
				5
				6
				7
				...

D

Appendix - EAWS

Ergonomic Assessment Worksheet V1.3.4

Plant	Gender of operator m ☐ f ☐	Body height
Line	MTM Analysis	Analyst
Task / Workplace	Task duration [sec]	Date

Result of overall evaluation: *Calculate the total score of the whole body sections and compare it to the upper limbs score. The overall result is determined by the higher value but interpretation should also take into account the second value.*

	Whole Body	=	Postures	+	Forces	+	Loads	+	Extra		Upper Limbs
☐ Green ☐ Yellow ☐ Red		=		+		+		+			

EAWS evaluation			
	0-25 Points	Green	Low risk: recommended; no action is needed
	>25-50 Points	Yellow	Possible risk: not recommended; redesign if possible, otherwise take other measures to control the risk
	>50 Points	Red	High risk: to be avoided; action to lower the risk is necessary

Extra points "Whole body" (per minute / shift)								**Extra points**
0a	Adverse effects by working on moving objects	0 none	3 middle	8 strong	15 very strong			Intensity
0b	Accessibility (e.g. entering motor or passenger compartment)	0 good	2 complicated	5 poor	10 very poor			Status
0c	Countershocks, impulses, vibrations	0 light	1 visible	2 heavy	5 very heavy			Intensity x frequency
		0 [n]	1 1 - 2	2,5 4 - 5	4 8 - 10	6 18 - 20	8 > 20	
0d	Joint position (especially wrist)	0 neutral	1 ~ 1/3 max	3 ~ 2/3 max	5 maximal			Intensity x duration or frequency
		0 [sec] [n] [%]	2 3 1 5	2,5 10 8 17	4 20 11 33	6 40 16 67	8 60 20 100	
0e	Other physical work load (please describe in detail)	0 none	5 middle	10 strong	15 very strong			Intensity
	Extra = ∑ lines 0a – 0e	Attention: Max. score = 40 (lines 0c, 0d); Max. score = 15 (lines 0a, 0c); Max. score = 10 (lines 0b)		Attention: correct evaluation, if duration of evaluation ≠ 60s				=

Lines 0a-b mainly relate to the Automotive industry, for other sectors additional elements may be necessary. For details see the EAWS manual.

For scoring of repetitive tasks only:		
Description	Formula	Result
Real shift duration [min]		
Lunch break [min]	-	
Other official pauses [min]	-	
Non repetitive tasks (i.e. cleaning, supplies, etc) [min]	-	
Net duration of repetitive task/s (a) [min]	=	
No. of real units (or cycles) (b)		
Net cycle time [sec]	(a/b x 60) =	
Observed cycle time [sec]		

Comments / proposals for improvements

EAWS form v1.3.4 © IAD and AMI 2013 1/4

Ergonomic Assessment Worksheet V1.3.4

Basic Positions / Postures and movements of trunk and arms (per shift) — Postures

(incl. loads of <3 kg,
forces onto fingers of <30 N
and whole body forces of <40 N)

Static postures: ≥ 4sec

High frequency movements:
Trunk bendings (> 60°) ≥ 2/min
Kneeling/crouching ≥ 2/min
Arm liftings (> 60°) ≥ 10/min

Evaluation of static postures and/or high frequent movements of trunk/arms/legs

$$\text{Duration [sec/min]} = \frac{\text{duration of posture(s)} \times 60}{\text{cycle time}}$$

No.	Posture	[%] 5 / [sec/min] 3 / [min/8h] 24	7,5 / 4,5 / 36	10 / 6 / 48	15 / 9 / 72	20 / 12 / 96	27 / 16 / 130	33 / 20 / 160	50 / 30 / 240	67 / 40 / 320	83 / 50 / 400	Sum of lines	Asymmetry effects: Trunk Rotation 1) (int 0-5, dur 0-3, Intensity x Duration)	Lateral Bending 1) (int 0-5, dur 0-3, Intensity x Duration)	Far Reach 2) (int 0-5, dur 0-2, Intensity x Duration)
Standing (and walking)															
1	Standing & walking in alteration, standing with support	0	0	0	0	0,5	1	1	1	1,5	2				
2	Standing, no body support (for other restrict. see Extra Points)	0,7	1	1,5	2	3	4	6	8	11	13				
3	Bent forward (20-60°)	2	3	5	7	9,5	12	18	23	32	40				
	with suitable support	1,3	2	3,5	5	6,5	8	12	15	20	25				
4	Strongly bent forward (>60°)	3,3	5	8,5	12	17	21	30	38	51	63				
	with suitable support	2	3	5	7	9,5	12	18	23	31	38				
5	Upright with elbow at / above shoulder level	3,3	5	8,5	12	17	21	30	38	51	63				
6	Upright with hands above head level	5,3	8	14	19	26	33	47	60	80	100				
Sitting															
7	Upright with back support slightly bent forward or backward	0	0	0	0	0	0	0,5	1	1,5	2				
8	Upright no back support (for other restrict. see Extra Points)	0	0	0,5	1	1,5	2	3	4	5,5	7				
9	Bent forward	0,7	1	1,5	2	3	4	6	8	11	13				
10	Elbow at / above shoulder level	2,7	4	7	10	13	16	23	30	40	50				
11	Hands above head level	4	6	10	14	20	25	35	45	60	75				
Kneeling or crouching															
12	Upright	3,3	5	7	9	12	15	21	27	36	45				
13	Bent forward	4	6	10	14	20	25	35	45	60	75				
14	Elbow at / above shoulder level	6	9	16	23	33	43	62	80	108	135				
Lying or climbing															
15	(Lying on back, breast or side) arms above head	6	9	15	21	29	37	53	68	91	113				
16	Climbing	6,7	10	22	33	50	66								
												∑ (a)	∑ (max.=15)	∑ (max.=15)	∑ (max.=10)
													∑ (max. = 40) (b)		

1) Trunk

	0	1	3	5
int	slightly ≤10°	medium 15°	strongly 25°	extreme ≥30°
	0	**1,5**	**2,5**	**3**
dur	never 0%	4 sec 6%	10 sec 15%	13 sec 20%

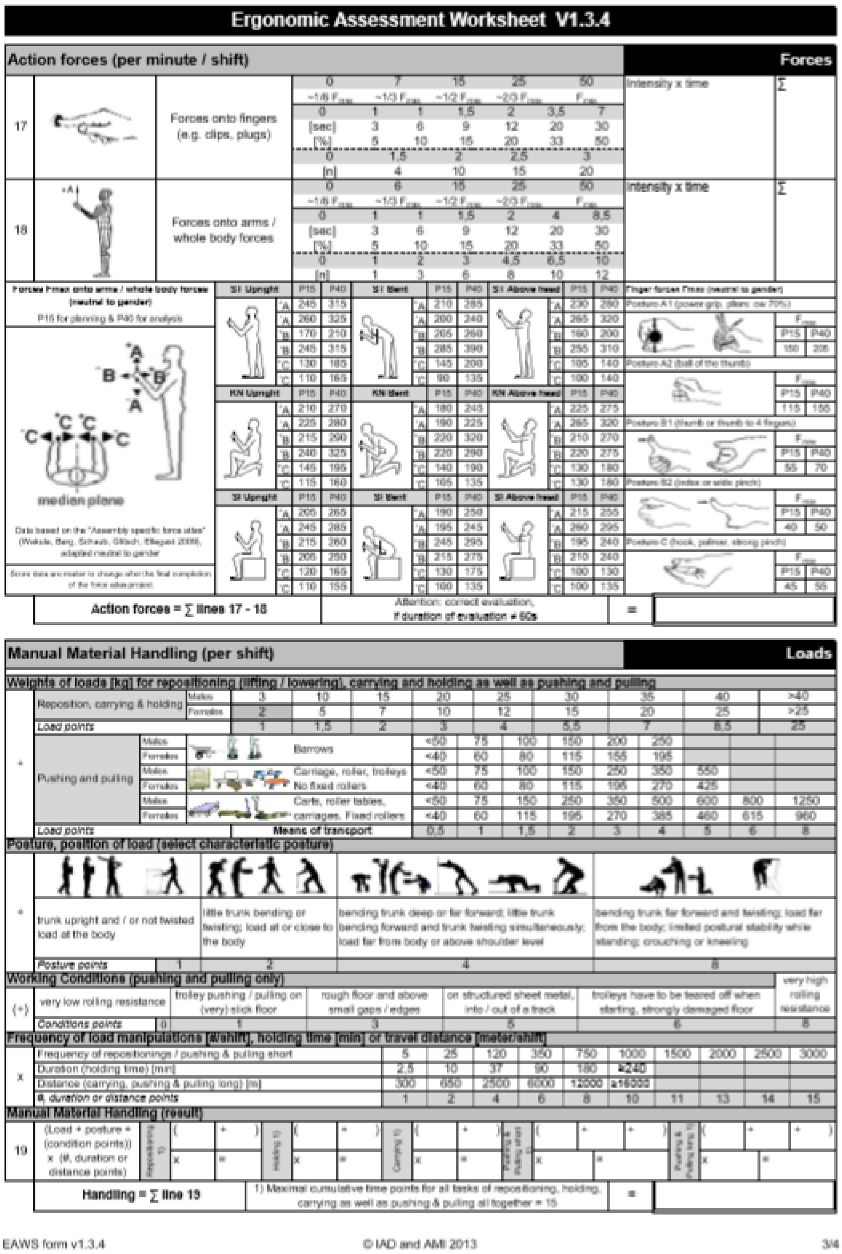
2) Far Reach

	0	1	3	5
int	close	50%	80%	arm stretched
	0	**1**	**1,5**	**2**
dur	never 0%	4 sec 6%	10 sec 15%	13 sec 20%

Attention: Max. duration of evaluation = duration of task or 100%!

Attention: correct evaluation, if duration of evaluation ≠ 60s

Postures = ∑ lines 1 - 16	(a)	+	(b)	=	



Ergonomic Assessment Worksheet V1.3.4

Action forces (per minute / shift) — Forces

17	Forces onto fingers (e.g. clips, plugs)		0	7	15	25	50		Intensity x time	Σ
			~1/6 F_{max}	~1/3 F_{max}	~1/2 F_{max}	~2/3 F_{max}	F_{max}			
		0	1	1	1,5	2	3,5	7		
		[sec]	3	6	9	12	20	30		
		[%]	5	10	15	20	33	50		
		0	1,5	2	2,5	3				
		[n]	4	10	15	20				
18	Forces onto arms / whole body forces		0	6	15	25	50		Intensity x time	Σ
			~1/6 F_{max}	~1/3 F_{max}	~1/2 F_{max}	~2/3 F_{max}	F_{max}			
		0	1	1	1,5	2	4	8,5		
		[sec]	3	6	9	12	20	30		
		[%]	5	10	15	20	33	50		
		0	1	2	3	4,5	6,5	10		
		[n]	1	3	6	8	10	12		

Forces Fmax onto arms / whole body forces (neutral to gender)
P15 for planning & P40 for analysis

	SI Upright P15	P40	SI Bent P15	P40	SI Above head P15	P40
A	245	315	210	285	230	280
A	260	325	200	240	265	320
B	170	210	205	260	160	200
B	245	315	285	390	255	310
C	130	185	145	200	105	140
C	110	165	90	135	100	140

	KN Upright P15	P40	KN Bent P15	P40	KN Above head P15	P40
A	210	270	180	245	225	275
A	225	280	190	225	265	320
B	215	290	220	320	210	270
B	240	325	220	290	220	275
C	145	195	140	190	130	180
C	115	160	105	135	130	180

	SI Upright P15	P40	SI Bent P15	P40	SI Above head P15	P40
A	205	265	190	250	215	255
A	245	285	195	245	260	295
B	215	260	245	295	195	240
B	205	250	215	275	210	240
C	120	165	130	175	100	130
C	110	155	100	135	100	135

median plane

Data based on the "Assembly specific force atlas" (Wakula, Berg, Schaub, Glitsch, Ellegast 2009), adapted neutral to gender

Some data are matter to change after the final completion of the force atlas project.

Finger forces Fmax (neutral to gender)

Posture	F_{max} P15	F_{max} P40
Posture A1 (power grip, pliers: ca 70%)	150	205
Posture A2 (ball of the thumb)	115	155
Posture B1 (thumb or thumb to 4 fingers)	55	70
Posture B2 (index or wide pinch)	40	50
Posture C (hook, palmar, strong pinch)	45	55

Action forces = ∑ lines 17 - 18 | Attention: correct evaluation, if duration of evaluation ≠ 60s | =

Manual Material Handling (per shift) — Loads

Weights of loads [kg] for repositioning (lifting / lowering), carrying and holding as well as pushing and pulling

Reposition, carrying & holding	Males	3	10	15	20	25	30	35	40	>40
	Females	2	5	7	10	12	15	20	25	>25
Load points		1	1,5	2	3	4	5,5	7	8,5	25

Pushing and pulling	Males	Barrows	<50	75	100	150	200	250			
	Females		<40	60	80	115	155	195			
	Males	Carriage, roller, trolleys No fixed rollers	<50	75	100	150	250	350	550		
	Females		<40	60	80	115	195	270	425		
	Males	Carts, roller tables, carriages. Fixed rollers	<50	75	150	250	350	500	600	800	1250
	Females		<40	60	115	195	270	385	460	615	960
Load points		Means of transport	0,5	1	1,5	2	3	4	5	6	8

Posture, position of load (select characteristic posture)

+	trunk upright and / or not twisted load at the body	little trunk bending or twisting; load at or close to the body	bending trunk deep or far forward; little trunk bending forward and trunk twisting simultaneously; load far from body or above shoulder level	bending trunk far forward and twisting; load far from the body; limited postural stability while standing; crouching or kneeling
Posture points	1	2	4	8

Working Conditions (pushing and pulling only)

(+)	very low rolling resistance		trolley pushing / pulling on (very) slick floor	rough floor and above small gaps / edges	on structured sheet metal, into / out of a track	trolleys have to be teared off when starting, strongly damaged floor	very high rolling resistance
Conditions points		0	1	3	5	6	8

Frequency of load manipulations [#/shift], holding time [min] or travel distance [meter/shift]

Frequency of repositionings / pushing & pulling short	5	25	120	350	750	1000	1500	2000	2500	3000
Duration (holding time) [min]	2,5	10	37	90	180	≥240				
Distance (carrying, pushing & pulling long) [m]	300	650	2500	6000	12000	≥16000				
#, duration or distance points	1	2	4	6	8	10	11	13	14	15

Manual Material Handling (result)

19	(Load + posture + (condition points)) x (#, duration or distance points)	Repositioning 1): (+) x =	Holding 1): (+) x =	Carrying 1): (+) x =	Pushing & Pulling short 1): (+ +) x =	Pushing & Pulling long 1): (+ +) x =

Handling = ∑ line 19 | 1) Maximal cumulative time points for all tasks of repositioning, holding, carrying as well as pushing & pulling all together = 15 | =

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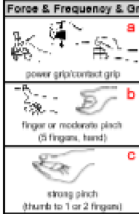
Ergonomic Assessment Worksheet V1.3.4

Upper limb load in repetitive tasks — Upper Limbs

Force & Frequency & Grip (FFG) — Basis: number of real actions per minute or percent static actions (analyze only the most loaded limb)



Force [N]	FFS (Force & Duration)	GS (Grip)	% (Percentage of time involved)	FFGp ((Force & Duration) + (Grip x Percentage of time involved))	≥45 (Very long lasting static actions; almost 75%)	30 (Long lasting static actions; almost 50%)	20 (Substantial amount of static actions ~ 30%)	10 (Considerable amount of static actions ~ 15%)	5 (Low amount of static actions ~ 10%)	3 (Very low amount of static actions < 5%)	0 (Good gripping conditions)	2 (Moderate gripping conditions)	4 (Poor gripping conditions)	2-5 (Seldom)	10 (Slow arm movements, freq. short interruptions)	15 (Arm movements not too fast, short interrupt.)	20 (Normal arm movements, but short or occasional and irregular interruptions)	25 (Faster arm movements, occasional and irregular short pauses)	30 (Continuous arm movements. Lack of interruptions make difficulties to keep pace)	35 (Very high frequencies, absolutely no interruptions)	≥40 (More)	FFG ((Force & Frequency) + Grip)	% (Percentage of time involved)	FFGp (((Force & Frequency) + Grip) x percentage)
	Calc Stat				Static actions (sec/min)						Grip			Dynamic actions (real actions/min)								Calc Dyn		
0 – 5					1	1	0	0	0	0	abc			0	0	0	1	2	3	4	7			
> 5 – 20					4	2	1	1	0	0	ab	bc		0	0	1	2	3	4	6	9			
> 20 – 35					7	5	3	2	1	1	ab	b	c	0	1	2	3	4	6	8	12			
> 35 – 90					11	8	5	3	2	1	a	b	b	1	2	3	5	7	9	12	18			
> 90 – 135					16	11	7	4	3	2	a	ab	b	2	3	5	7	9	12	15	24			
> 135 – 225					21	14	10	6	4	3	a	a	b	4	5	6	8	11	14	20	32			
> 225 – 300					28	18	12	8	5	4	a	a	b	5	6	7	9	12	16	26	40			

S D

20a — ΣFLSi = 100% — FFGS = ∑ FFGp — 100% — FFG = FFGS + FFGD — FFG — %DA = ΣFLDj — FFGD = ∑ FFGp — %DA

Hand / arm / shoulder postures (use duration for worst case of wrist / elbow / shoulder)

20b — Wrist (deviaton, flex./extens.) — Elbow (pron, sup, flex./extens.) — Shoulder (flexion, extension, abduction)

Posture points	10%	25%	33%	50%	65%	85%	PP
	0	0,5	1	2	3	4	

Additional factors

20c	Gloves inadequate (which interfere with the handling ability required) are used for over half the time	2	☐
	Working gestures required imply a countershock. Frequency of 2 time per minute or more (i.e.: hammering over hard surface)	2	☐
	Working gestures imply a countershock (using the hand as a tool) with freq. of 10 time per hour or more	2	☐
	Exposure to cold or refrigeration (less than 0 degree) for over half the time	2	☐
	Vibrating tools are used for 1/3 of the time or more	2	☐
	Tools with a very high level of vibrations	4	☐
	Tools employed cause compressions of the skin (rednesses, callosities, blebs, etc.)	2	☐
	Precision tasks are carried out for over half the time (tasks over areas smaller than 2-3 mm)	2	☐
	More than one additional factor is present at the same time and overall occupy the whole of the time	3	☐
	Additional points (choose the highest value)	=	AF

Repetitive tasks duration

20d										
Duration [h/shift]	< 1		1,5	3		5	7	> 8		+
Duration Points	1		1,5	3		5	7	10		
Work Organization	Breaks are possible at every time (Cycle time longer than 10 minutes)		Breaks are possible at given conditions (Cycle time between 1 and 10 minutes)				Breaks lead to a stop of the process (Cycle time shorter than 1 minute)			+
Work Organization Points	0		1				2			
Breaks (≥ 8 min) [#/shift]	0	1	2	3	4	5	6	≥7		+
Break points — *cycle time ≤ 30 sec*	3	2	1	0	-1	-2	-3	-4		
cycle time > 30 sec	0		-0,5		-1		-1,5	-2		
Duration Points										= DP

Upper limb load in repetitive tasks

20	(a) Force & Frequency & Grip		(b) Postures		(c) Additional factors		(d) Duration		Upper Limbs
	(FFG	+	PP	+	AF)	x	DP	=	

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E

Appendix - KIM I

ASSESSMENT OF MANUAL HANDLING TASKS BASED ON KEY INDICATORS Version 2001

Where there are a number of individual activities with considerable physical strains, they must be estimated separately.

Workplace/Activity:

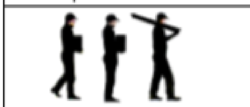
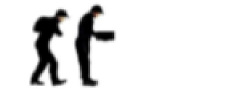
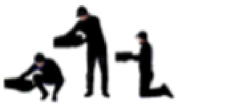
1st step: Determination of time rating points *(Select only one column !)*

Lifting or displacement operations (< 5 s)		Holding (> 5 s)		Carrying (> 5 m)	
Number on working day	**Time rating points**	*Total duration on working day*	**Time rating points**	*Overall length on working day*	**Time rating points**
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	6	1 hrs to < 2 hrs	6	4 to < 8 km	6
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
≥ 1000	10	≥ 4 hrs	10	≥ 16 km	10
Examples: • *laying bricks,* • *placing workpieces into a machine* • *taking boxes out of a container and putting them onto a conveyor belt*		*Examples:* • *holding and guiding a cast iron slug while working on a wheel stand,* • *operating a hand grinding machine,* • *operating a weed-eater*		*Examples:* • *furniture removal,* • *delivering scaffolding parts to a building site*	

2nd step: Determination of rating points of load, posture and working conditions

Effective load[1] for men	Load rating point	Effective load[1] for women	Load rating point
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to <10 kg	2
20 to < 30 kg	4	10 to <15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
≥ 40 kg	25	≥ 25 kg	25

1) „Effective load" means in this context the real action force which is necessary for moving load. This action force does not correspond to the load mass in each case. When tilting a carton, only 50 % of the load mass will have an effect on worker and when using a cart only 10 %.

Typical posture, position of load[2]	Posture, position of load	Posture rating point
	• Upper body upright, not twisted • When lifting, holding, carrying und lowering the load is close to body	1
	• Slightly bending forward or twisting the trunk • When lifting, holding, carrying und lowering load is near to medium to body	2
	• Low bending or far bending forward • Slightly bending forward with simultaneous twisting of trunk • Load far from the body or above shoulder height	4
	• Bending far forward with simultaneous twisting of trunk • Load far from body • Restricted stability of posture when standing • Crouching or kneeling	8

2) To determine the posture rating points the typical posture during manual handling must be used. For example when there are different postures with load a mean value must be used – not occasional extreme values.

Working conditions	Working conditions rating point
Good ergonomic conditions, e.g. sufficient space, no physical obstacles within the workspace, even level and solid flooring, sufficient lighting, good gripping conditions	0
Space for movement restricted and unfavourable ergonomic conditions (e.g. 1: space for movement restricted by too low high or working area less than 1,5 m² or 2: posture stability impaired by uneven floor or soft ground)	1
Strongly restricted space of movement and/or instability of centre of gravity of load (e.g. transfer of patients)	2

3rd step: Evaluation

The rating points relevant to this activity are to be entered and calculated in the diagram.

	Load rating points				
+	Posture rating points				
+	Working conditions rating points				
=	Total	x	Time rating points	=	Risk score

On the basis of the rating calculated and the table below it is possible to make a rough evaluation. [3] Regardless of this provisions of the Maternity Leave Act apply.

Risk range	Risk score	Description
1	< 10	Low load situation, physical overload unlikely to appear.
2	10 bis < 25	Increased load situation, physical overload is possible for less resilent persons[4]. For that group redesign of workplace is helpful.
3	25 bis < 50	Highly increased load situation, physical overload also possible for normal persons. Redesign of the workplace is recommended.
4	≥ 50	High load situation, physical overload is likely to appear. Workplace redesign is necessary[5].

3) Basically it must be assumed that as the number of point rating rises, so the risk of overloading the muscular-skeletal system increases. The boundaries between the risk ranges are fluid because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an orientation aid. More exact analyses require specialist ergonomic knowledge.

4) Less resilent persons in this context are persons older than 40 or younger than 21 years, newcomers in the job or people suffering from illness.

5) Design requirements can be determinated with reference to the number of point in the table. By reducing the weight, improving the execution conditions or shortening the strain time, elevated stress can be avoided.

Check of the workplace necessary for other reasons: ☐

Reasons: ____

____

____

Date of assessment: ________________ Assessed by: ________________________

Ed. by •Federal Institute for Occupational Safety and Health and •Committee of the Laender for Occupational Safety and Health (•Bundesanstalt für Arbeitsschutz und Arbeitsmedizin - BAuA und •Länderausschuss für Arbeitsschutz und Sicherheitstechnik - LASI) 2001

F

Appendix - KIM II

Assessment of pulling and pushing based on key indicators *Version Sept. 2002*

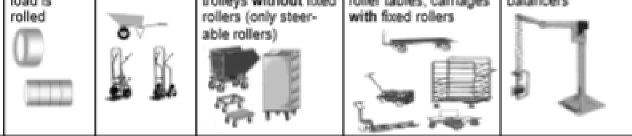
The overall activity must be broken down into individual activities. Each individual activity involving major physical strain must be assessed separately.

Workplace/Activity:

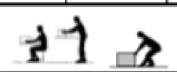
1st step: Determination of time rating points *(Select only one column)*

Pulling and pushing over short distances or frequent stopping (single distance up to 5 metres)		Pulling and pushing over longer distances (single distance more than 5 metres)	
Number on working day	**Time rating points**	*Total distance on working day*	**Time rating points**
< 10	1	< 300 m	1
10 to < 40	2	300 m to < 1km	2
40 to < 200	4	1 km to < 4 km	4
200 to < 500	6	4 to < 8 km	6
500 to < 1000	8	8 to < 16 km	8
≥ 1000	10	≥ 16 km	10
Examples: operation of manipulators, setting up machines, distribution of meals in a hospital		*Examples: garbage collection, furniture transport in buildings on rollers, unloading and transloading of containers*	

2nd step: Determination of rating points of mass, positioning accuracy, speed, posture and working conditions



Mass to be moved (load weight) **rolling**	Industrial truck, aid: Without, load is rolled	Barrow	Carriage, roller, trolleys **without** fixed rollers (only steerable rollers)	Rail cars, hand carts, roller tables, carriages **with** fixed rollers	Manipulators, rope balancers
< 50 kg	0.5	0.5	0.5	0.5	0.5
50 to < 100 kg	1	1	1	1	1
100 to < 200 kg	1.5	2	2	1.5	2
200 to < 300 kg	2	4	3	2	4
300 to < 400 kg	3		4	3	
400 to < 600 kg	4		5	4	
600 to <1000 kg	5			5	
≥ 1000 kg					



sliding	
< 10 kg	1
10 to < 25 kg	2
25 to < 50 kg	4
> 50 kg	

Grey areas:
Critical because a check of the movement of industrial truck/load depends very much on skill and physical strength.

White areas without number:
Basically to be avoided because the necessary action forces can easily exceed the maximum physical forces.

Positioning accuracy	Speed of motion: slow (< 0.8 m/s)	fast (0.8 bis 1.3 m/s)
Low - no specification of travelling distance - load can roll to a stop or runs against a stop	1	2
High - load must be accurately positioned and stopped - travelling distance must be adhered to exactly - frequent changes in direction	2	4

Note: the average walking speed is approx. 1 m/s

Assessment of pulling and pushing based on key indicators *Version Sept. 2002*

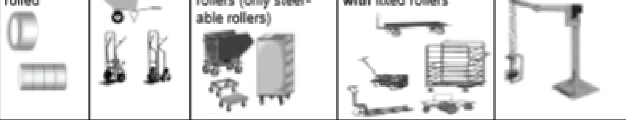
The overall activity must be broken down into individual activities. Each individual activity involving major physical strain must be assessed separately.

Workplace/Activity:

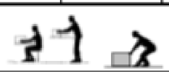
1st step: Determination of time rating points *(Select only one column)*

Pulling and pushing over short distances or frequent stopping (single distance up to 5 metres)		Pulling and pushing over longer distances (single distance more than 5 metres)	
Number on working day	**Time rating points**	*Total distance on working day*	**Time rating points**
< 10	1	< 300 m	1
10 to < 40	2	300 m to < 1km	2
40 to < 200	4	1 km to < 4 km	4
200 to < 500	6	4 to < 8 km	6
500 to < 1000	8	8 to < 16 km	8
≥ 1000	10	≥ 16 km	10
Examples: operation of manipulators, setting up machines, distribution of meals in a hospital		*Examples: garbage collection, furniture transport in buildings on rollers, unloading and transloading of containers*	

2nd step: Determination of rating points of mass, positioning accuracy, speed, posture and working conditions



Mass to be moved (load weight) rolling	Industrial truck, aid: Without, load is rolled	Barrow	Carriage, roller, trolleys **without** fixed rollers (only steerable rollers)	Rail cars, hand carts, roller tables, carriages **with** fixed rollers	Manipulators, rope balancers
< 50 kg	0.5	0.5	0.5	0.5	0.5
50 to < 100 kg	1	1	1	1	1
100 to < 200 kg	1.5	2	2	1.5	2
200 to < 300 kg	2	4	3	2	4
300 to < 400 kg	3		4	3	
400 to < 600 kg	4		5	4	
600 to <1000 kg	5			5	
≥ 1000 kg					



sliding	
< 10 kg	1
10 to < 25 kg	2
25 to < 50 kg	4
> 50 kg	

Grey areas:
Critical because a check of the movement of industrial truck/load depends very much on skill and physical strength.

White areas without number:
Basically to be avoided because the necessary action forces can easily exceed the maximum physical forces.

Positioning accuracy	Speed of motion: slow (< 0.8 m/s)	fast (0.8 bis 1.3 m/s)
Low - no specification of travelling distance - load can roll to a stop or runs against a stop	1	2
High - load must be accurately positioned and stopped - travelling distance must be adhered to exactly - frequent changes in direction	2	4

Note: the average walking speed is approx. 1 m/s

G

Appendix - KIM III

Key indicator method for assessing physical workload during manual handling operations
If a number of different tasks are performed within one one working day, they must be recorded separately.

task

Version 2012

1st step: Determination of time rating points

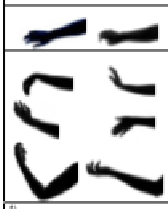
Total duration of this activity per shift [up to … hours]	1	2	3	4	5	6	7	8	9	10
Time rating points	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**

2nd step: Determination of the rating points for the type of force exertion, gripping conditions, work organisation, working conditions, posture and hand/arm position and movement

Type of force exertion(s) in the finger-hand area		**Holding** average holding time [secs per minute]				**Moving** average movement frequencies [number per minute]				
		60-31	30-16	15-4	<4 / <1	1-4	5-15	16-30	31-60	>60
Level	**Description, typical examples**	**Rating points**								
low	**Very low forces** e.g. button actuation / shifting / ordering	**2**	**1**	**0.5**	**0**	**0**	**0.5**	**1**	**2**	**3**
	Low forces e.g. material guidance / insertion	**3**	**1.5**	**1**	**0**	**0**	**1**	**1.5**	**3**	**5**
	Moderate forces e.g. gripping / joining small work pieces by hand or with small tools	**5**	**2**	**1**	**0**	**0.5**	**1**	**2**	**5**	**8**
	High forces e.g. turning / winding / packaging / grasping / holding or joining parts / pressing in / cutting/ Working with small powered hand tools	**8**	**4**	**2**	**0,5**	**1**	**2**	**4**	**8**	**13**
	Very high forces e.g. cutting involving major element of force / working with small staple guns / moving or holding parts or tools	**12**	**6**	**3**	**1**	**1**	**3**	**6**	**12**	**21**
	Peak forces e.g. tightening, loosening bolts / separating / pressing in	**19**	**9**	**4**	**1**	**2**	**4**	**9**	**19**	**33**
high	**Hitting** with ball of the thumb, palm of the hand or fist	-	-	-	**1**	**1**	**3**	**6**	**12**	**21**

The work cycle must be observed and the rating points for the force categories marked. Added together (left and right hands separately) these produce the force rating point. To calculate the total point rating values the higher figure must be used.	**Rating points of force exertion:**	**Left hand:**	**Right hand:**

Force transfer / Gripping conditions	**Rating 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



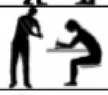
Hand/arm position and movement *)	**Rating points**
Good: position or movements of joints in the medium (relaxed) range / only rare deviations	0
Restricted: occasional positions or movements of the joints at the limit of the movement ranges	1
Unfavourable: frequent positions or movements of the joints 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

*) *Typical positions are to be considered. Rare deviations can be ignored.*

Work organisation	**Rating 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

Features not mentioned in the table are to be taken into account accordingly.

Working conditions	Rating points
Good: reliable recognition of detail / no dazzle / good climatic conditions	0
Restricted: impaired detail recognition due to dazzle or excessively small details / draughts / cold / wet / disturbed concentration due to noise	1
Features not mentioned in the table are to be taken into account accordingly. Under highly unfavourable conditions rating point 2 can be assigned.	

	Posture **)	Rating 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
***) Typical postures are to be taken into account. Rare deviations can be ignored.*		

3rd step: Evaluation

Enter the rating points applicable for the activities and calculate the risk score in the diagram.

	Type of force exertion(s) in the finger-hand range	
+	Force transfer/gripping conditions	
+	Hand/arm position and movement	
+	Work organisation	
+	Working conditions	
+	Posture	
=	Total	

Total **x** Time rating points **=** Risk score

On the basis of the risk score calculated and the table below it is possible to make a rough evaluation.

Risk range ***)	Risk score	Description
1	<10	Low load situation, health risk from physical overload is unlikely to appear.
2	10 to <25	Moderate load situation, physical overload is possible for less resilient persons. For this group redesign of workplace is helpful.
3	25 to <50	Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.
4	≥50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.

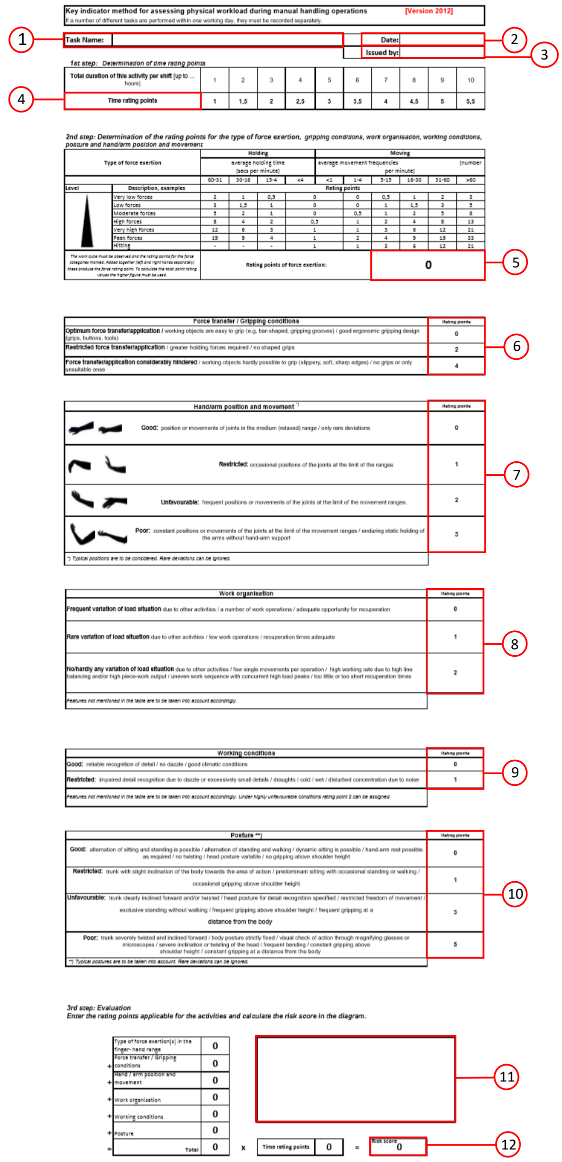
****) The boundaries between the risk ranges are fluid because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an **orientation aid**. Basically it must be assumed that as the number of risk scores rises, so the risk of overloading the muscular-skeletal system increases.*

Published by the Federal Institute for Occupational Safety and Health 2012 www.baua.de

H

Appendix - Digital KIM III with explanation

1. Automatically updates the task name with the IPS scene name if one is available.
2. Automatically inserts todays date.
3. Automatically enters the CEVT user ID of the computer.
4. The result of question 1 will be displayed here.
5. A calculated value based on question 2, 3 and 4, will be displayed here.
6. The result of question 5 will be displayed here.
7. A score will be given based on the manikin's arms and hands position.
8. The result of question 6 will be displayed here.
9. The result of question 7 will be displayed here.
10. A score will be given based on the manikin's body posture.
11. A snapshot of the IPS window will be visible here.
12. The total risk score will give an overall score of the load situation based on all criteria's above.



I

Appendix - HARM

Assessment form
Hand Arm Risk-assessment Method (HARM)

HARM 2.0

Task	Date ....
Department/job	Completed by ....

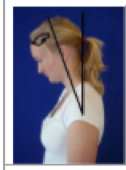
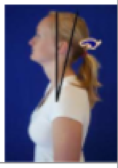
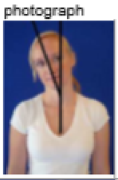
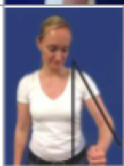
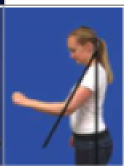
Step 1.	**Task duration score**	
Step 1A:	The total time duration of the task over the course of an 'average working day' (all time periods should be added together). Indicate the time duration only for the days that the task occurs (10 hours maximum).	... hours - 1 = ...
Step 1B:	How many days per week does the task occur? - for 1 or 2 days per week: deduct 1 point from the score: - for 3 or more days, the score remains the same:	- 1 - 0
Step 1C:	Is a break of at least 7.5 minutes* taken every 1.5 hours? - Yes; deduct 1 point from the score - No; the score remains the same:	-1 -0
* Read the annex for what is meant by a break		
Step 1D:	**Calculate the task duration score** — If the task duration score is less than 1, then the score is 1	....

Step 2. **Most active hand** Circle the most active arm/hand during the task: **right / left**
continue with step 3 till 8 for this hand

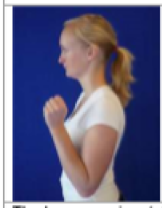
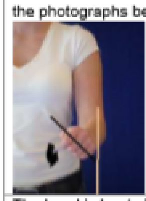
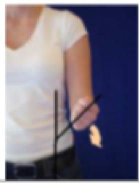
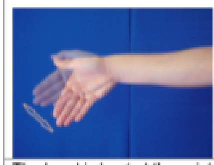
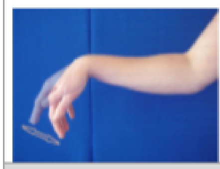
Step 3. **Force score**							
Step 3A		**Step 3B**			**Step 3C**		
Indicate which hand is the most active *very similar forces should be assessed as one and the same force*		**Duration of the force exertion in seconds per minute**			**Number of force exertions per minute (frequency)** *(skip if frequency is smaller than 1x/min)*		
Amount of force	**Description and examples**	<4	4-30	>30	1- 4	4-30	≥ 30
(extremely) low to average: weight < 100 g to 1 kg force < 1 N to 10 N	Light pressure with fingers to holding/ grasping. For example: - sorting letters/objects, - pressing with the fingers, - using hand to hold small electric tools - grasping/gripping, holding or attaching parts, pressing firmly	0	2	3,5	1	2,5	4
somewhat high to high: weight: 1-6 kg force: 10-60 N	Holding firmly with hand to high force exertion by the arm. For example: - use of a knife/pliers, - using tools, - pushing heavy objects (e.g. cashier operator), - holding heavy tools, operating a stiff lever	0	4	6,5	2	4	6,5
peakforce	Striking with flat hand/fist e.g. hammer	-	-	-	3	5	8

Step 3D **Force score = highest score circled =** ....

In the event of **high forces**: *Please note!* If the force exertion is more than 6 kg, these must be assessed using a different method (e.g. lifting, or pushing/pulling risk assessment method).

Step 4A	**Posture score for the HEAD/NECK and the SHOULDER/UPPER ARM**	**The percentage of the task duration that the posture occurs:**		
		<10%	**10-50%**	**>50%**
The head is tilted further forward than in the first photograph OR further back than in the second photograph  	The head is tilted further sideways than in the first photograph OR the head is turned, as in the second photograph  	0	1,5	3
The head is tilted forward **and turned at the same time**		0	2	4
The head is tilted backward **and turned at the same time**		0	3	4
Head (chin) pushed (extended) forward		0	1,5	3
With the arm **unsupported**, the upper arm is further forward OR sideways of the trunk than in the photographs OR angled behind the trunk	 	0	2,5	3,5
Shoulders raised (high)		0	3	4
Determine 'posture score for neck/shoulder' = highest score =		-------------------		

2

Step 4B Posture score for the WRIST/LOWER ARM		The percentage of the task duration that the posture occurs:		
		<10%	10-50%	>50%
Elbow significantly bent or extended				
		0	1	2
The lower arm is rotated further (in the direction of the arrows) than in the photographs below 		0	1	2
The hand is bent sideways (in the direction of the little finger and/or thumb) at the wrist so that the position of the wrist is between the positions shown in the photographs. 		0	1,5	3
The hand is bent at the wrist so that the position of the wrist is between the positions shown in the photographs 		0	1,5	3
Determine 'posture score for lower arm/wrist' = highest score =		....		

Step 5. Vibration score

Are vibrating tools used?

- **No, insert '0' for the vibration score in the grey boxes below and proceed to Step 6**
- **Yes, is the vibration intensity known?**
  - **No, go to Step 5A: the vibration intensity is unknown**
  - **Yes, go to Step 5B: the vibration intensity is known**

Step 5A **The vibration intensity is unknown**		
Which of the situations applies? Circle the corresponding score and put this in the grey box at the bottom of the table.	**Duration of exposure within the task**	
	0-4 hours	**4-8 hours**
Description	**Score**	
Hardly any vibration, or no vibrations perceived by the user or visible to the assessor	0	0
Vibrations not visible, but perceived by the user (quivering sensation)	2	2
Vibrations just visible on the lower arm/hand, clearly perceived by the user	2	4
The hands, arms or shoulders can be clearly seen to vibrate and vibrations are clearly perceived by the user	4	4
Vibration score: use the circled score:	------	------

Step 5B **The vibration intensity is known**		
	Score	
Which of the situations applies? Circle the corresponding score and place this in the grey box at the bottom of the table.	**Duration of exposure for the task**	
Vibration intensity	**0-4 hours**	**4-8 hours**
< 2,5 m/s^2	0	0
≤ 2,5 - 5 m/s^2	2	2
≤ 5 – 10 m/s^2	2	4
≥ 10 m/s^2	4	4
Score for vibration: use the circled score:	------	------

Step 6. Other factors:

Indicate whether the following situation apply to the task	**Circle the correct answer**
Breaks can only be taken at set break times (as opposed to breaks taken at the employee's discretion)	Yes/no
Work with cold or wet materials is performed without gloves	Yes/no
Disruption to concentration occurs regularly (only if work requires concentration)?	Yes/no
Hand grips are not shaped or are slippery or wet. Stretched fingers or a 2- or 3-finger pinch grip often occur because large or small materials are gripped or held	Yes/no
The work performed is a precision task. It requires precise positioning or moving of fingers or hands, such as assembly of very small pieces or surgical actions	Yes/no
Score for other factors: 0,5 for each 'yes' above:	------

4

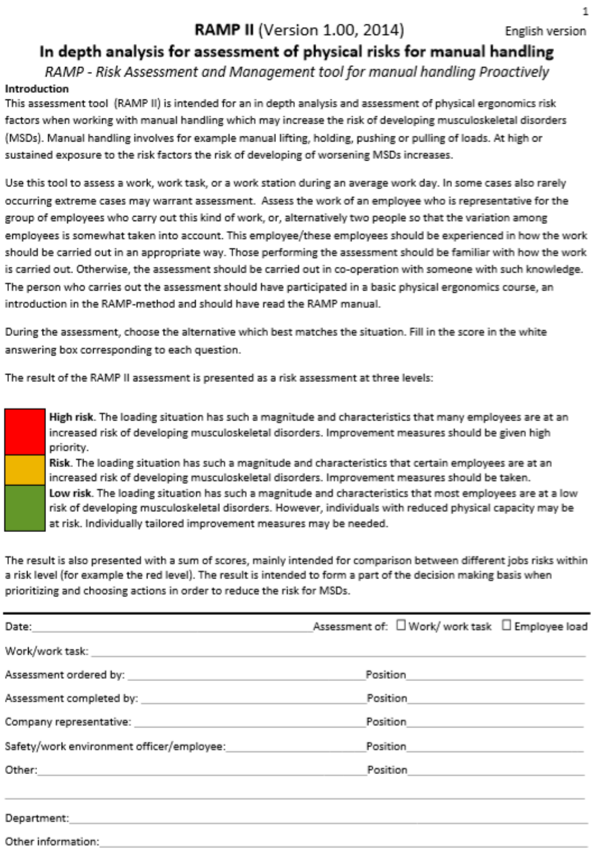
Step 7. Calculate total risk score	
Use the scores from steps 1 through 6	Scores:
Force score (step 3)	....
Posture score for the neck/shoulder (Step 4A)	....
Posture score for the lower arm/wrist (Step 4B)	....
Vibration score (Step 5)	....
Other factor score (Step 6)	.... +
Calculate total score (A):	....
Task duration score (taken from step 1) (T)	 X
Calculate risk score (task duration score (T) X total score (A))	....

Step 8. Risk assessment:		
Determine the risk of experiencing complaints when performing the task by using the table below:		
Total score	Risk	Description
<30	GREEN	**No risk** of arm, neck or shoulder complaints for virtually the entire working population.
30-50	AMBER	**Increased risk** of arm, neck or shoulder complaints for some employees. In order to protect all employees, it is important to take preventative **measures** that lower the risk.
≥50	RED	**High risk** of arm, neck or shoulder complaints. It is important to **take preventative measures immediately.**
Health complains		**If there are complaints that are suspected to be related to the task, it is ALWAYS important to identify the risk factors and take preventative measures!**

5

J

Appendix - RAMP



1

RAMP II (Version 1.00, 2014) English version

In depth analysis for assessment of physical risks for manual handling

RAMP - Risk Assessment and Management tool for manual handling Proactively

Introduction

This assessment tool (RAMP II) is intended for an in depth analysis and assessment of physical ergonomics risk factors when working with manual handling which may increase the risk of developing musculoskeletal disorders (MSDs). Manual handling involves for example manual lifting, holding, pushing or pulling of loads. At high or sustained exposure to the risk factors the risk of developing of worsening MSDs increases.

Use this tool to assess a work, work task, or a work station during an average work day. In some cases also rarely occurring extreme cases may warrant assessment. Assess the work of an employee who is representative for the group of employees who carry out this kind of work, or, alternatively two people so that the variation among employees is somewhat taken into account. This employee/these employees should be experienced in how the work should be carried out in an appropriate way. Those performing the assessment should be familiar with how the work is carried out. Otherwise, the assessment should be carried out in co-operation with someone with such knowledge. The person who carries out the assessment should have participated in a basic physical ergonomics course, an introduction in the RAMP-method and should have read the RAMP manual.

During the assessment, choose the alternative which best matches the situation. Fill in the score in the white answering box corresponding to each question.

The result of the RAMP II assessment is presented as a risk assessment at three levels:

High risk. The loading situation has such a magnitude and characteristics that many employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority.

Risk. The loading situation has such a magnitude and characteristics that certain employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be taken.

Low risk. The loading situation has such a magnitude and characteristics that most employees are at a low risk of developing musculoskeletal disorders. However, individuals with reduced physical capacity may be at risk. Individually tailored improvement measures may be needed.

The result is also presented with a sum of scores, mainly intended for comparison between different jobs risks within a risk level (for example the red level). The result is intended to form a part of the decision making basis when prioritizing and choosing actions in order to reduce the risk for MSDs.

Date:______ Assessment of: ☐ Work/ work task ☐ Employee load

Work/work task:______

Assessment ordered by:______ Position______

Assessment completed by:______ Position______

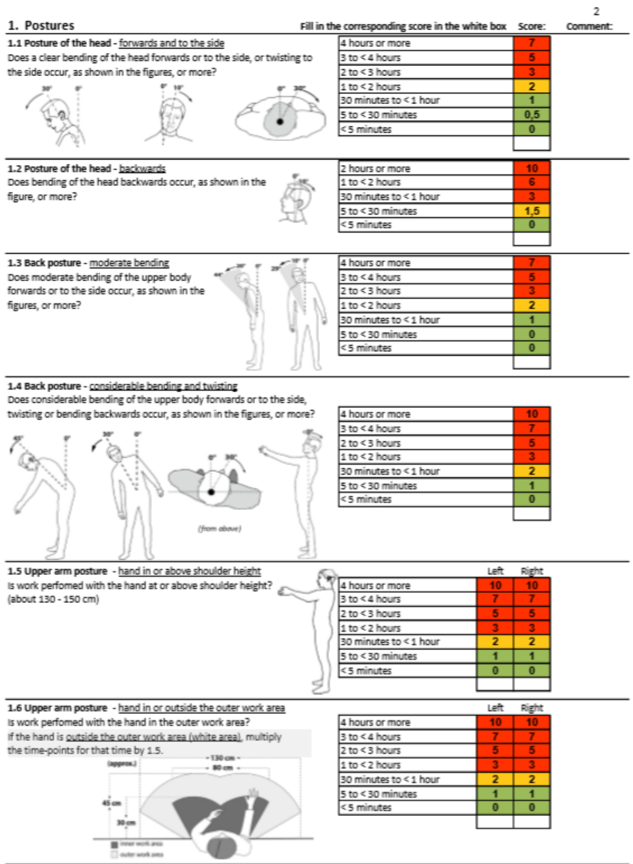
Company representative:______ Position______

Safety/work environment officer/employee:______ Position______

Other:______ Position______

Department:______

Other information:______



2

1. Postures — Fill in the corresponding score in the white box — Score: — Comment:

1.1 Posture of the head - forwards and to the side

Does a clear bending of the head forwards or to the side, or twisting to the side occur, as shown in the figures, or more?

	Score
4 hours or more	7
3 to < 4 hours	5
2 to < 3 hours	3
1 to < 2 hours	2
30 minutes to < 1 hour	1
5 to < 30 minutes	0,5
< 5 minutes	0

1.2 Posture of the head - backwards

Does bending of the head backwards occur, as shown in the figure, or more?

	Score
2 hours or more	10
1 to < 2 hours	6
30 minutes to < 1 hour	3
5 to < 30 minutes	1,5
< 5 minutes	0

1.3 Back posture - moderate bending

Does moderate bending of the upper body forwards or to the side occur, as shown in the figures, or more?

	Score
4 hours or more	7
3 to < 4 hours	5
2 to < 3 hours	3
1 to < 2 hours	2
30 minutes to < 1 hour	1
5 to < 30 minutes	0
< 5 minutes	0

1.4 Back posture - considerable bending and twisting

Does considerable bending of the upper body forwards or to the side, twisting or bending backwards occur, as shown in the figures, or more?

(from above)

	Score
4 hours or more	10
3 to < 4 hours	7
2 to < 3 hours	5
1 to < 2 hours	3
30 minutes to < 1 hour	2
5 to < 30 minutes	1
< 5 minutes	0

1.5 Upper arm posture - hand in or above shoulder height

Is work perfomed with the hand at or above shoulder height? (about 130 - 150 cm)

	Left	Right
4 hours or more	10	10
3 to < 4 hours	7	7
2 to < 3 hours	5	5
1 to < 2 hours	3	3
30 minutes to < 1 hour	2	2
5 to < 30 minutes	1	1
< 5 minutes	0	0

1.6 Upper arm posture - hand in or outside the outer work area

Is work perfomed with the hand in the outer work area?

If the hand is outside the outer work area (white area), multiply the time-points for that time by 1.5.

	Left	Right
4 hours or more	10	10
3 to < 4 hours	7	7
2 to < 3 hours	5	5
1 to < 2 hours	3	3
30 minutes to < 1 hour	2	2
5 to < 30 minutes	1	1
< 5 minutes	0	0

3

Fill in the corresponding score in the white box | Score: | Comment:

1.7 Wrist posture
Is work performed with clearly bent wrist, as shown in the figures, or more?

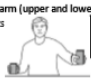
	Left	Right
4 hours or more	7	7
3 to < 4 hours	5	5
2 to < 3 hours	3	3
1 to < 2 hours	2	2
30 minutes to < 1 hour	1	1
5 to < 30 minutes	0	0
< 5 minutes	0	0

1.8 Leg and foot space and surface
Is there a lack of space for the legs or for the feet, or is the surface unstable or sloping?

4 hours or more	3
3 to < 4 hours	2
2 to < 3 hours	1,5
1 to < 2 hours	1
30 minutes to < 1 hour	0,5
5 to < 30 minutes	0
< 5 minutes	0

2. Work movements and repetitive work

2.1 Movements of the arm (upper and lower arm)
How are the movements of the arm generally?

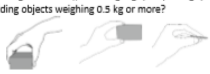


	Left	Right
Constant movements mainly without pause	5	5
Frequent movements with some pauses	2	2
Varied movements, movement now and then (up to 2/min)	0	0

2.2 Movements of the wrist
Do similar movements of the wrist occur?

	Left	Right
More than 20 times per minute	5	5
11 - 20 times per minute	3	3
6 - 10 times per minute	1	1
Up to 5 times per minute	0	0

2.3 Type of grip - frequency
Is overhand grip (palm facing downward), wide finger grip or pinch grip used while lifting or holding objects weighing 0.5 kg or more?



	Left	Right
More than 200 times per day	4	4
101 - 200 times per day	2	2
50 - 100 times per day	1	1
Less than 50 times per day	0	0

2.4 Shorter recovery/variation during work (mainly regarding the neck, the arms and the back)
Assessment of whether or not the work enables sufficient variation or breaks so that muscle groups under strain are given time to recover. The variation or break has to be at least 5 seconds at a time to be eligible.
Approximately, how much of the working time consists of such variation or breaks generally?

30 seconds or less per 10 minutes work	10
Between 30 and 90 seconds per 10 minutes work	4
90 seconds or more per 10 minutes work	0

2.5 Longer recovery/variation during work (not breaks, e.g. task rotation that gives sufficient recovery)
Assessment of whether or not the work enables sufficient variation or breaks so that muscle groups under strain are given time to recover. The variation or break has to be at least 5 minutes when totalled together to be eligible.
Approximately, how often does such variation or breaks occur during the work generally?

Every 4 hours or less frequently	10
Every 3 hours	6
Every second hour	3
Every hour	0

4

3. Lifting work

Fill in the corresponding score in the white box | Score:

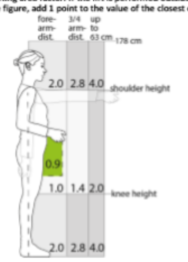
If no lifts occur: Write 0 in the box on the right and go to 4. — No lifting work: 0
Make an assessment for an average case. Frequent handling of light loads (< 1 kg) is covered in other parts of RAMP II.

1. Estimate the weight of the load and how often it is lifted to determine the Frequency-and-weight factor (Table 1).
2. Estimate in what work area the lifting is carried out (Table 2) using the posture of the hands (height and distance) at the start and at the end of the lift. Use the largest of these values.
3. Calculate the Risk score in Table 3 by:
   a. inserting the values from Table 1 and Table 2 into Table 3.
   b. assessing the other factors on the list in Table 3 and use these when calculating the Risk score in Table 3.
   c. multiplying the factors in the column on the right in Table 3 with each other.
4. Insert this Risk score as "Risk score 1" in the box on the right at the bottom.
5. If single lifts which are perceived as particularly strenuous occur, these should be assessed separately. If so, do the same for that case, i.e. perform step 1-3.
6. If a worst case is analysed, insert its Risk score in the box "Risk score 2" on the right at the bottom. If no worst case is analysed, insert the Risk score for the average case (i.e. "Risk score 1") also in the "Risk score 2" box. Beside it information about if the Risk score corresponds to green, yellow or red risk level is displayed.

Table 1: Frequency-and-weight factor.

	Number of lifts per day	≤ 12	13 - 24	25 - 60	61 - 96	97 - 240	241 - 480	481 - 960	961-1920	1921-2880	2881-3840	3841-4800
	Equals number of lifts per hour	≤ 1.5	1.6 - 3	3.1 - 7.5	7.6 - 12	13 - 30	31 - 60	61 - 120	121 - 240	241 - 360	361 - 480	481 - 600
Weight	over 25 kg - 30 kg	6.5	6.5	7.0	7.6	8.0	8.6	9.9	14.3	23.9	35.9	49.7
	over 20 kg - 25 kg	5.4	5.4	5.8	6.3	6.6	7.1	8.3	12.0	19.9	29.9	41.4
	over 15 kg - 20 kg	4.3	4.4	4.7	5.1	5.3	5.7	6.6	9.6	15.9	23.9	33.1
	over 10 kg - 15 kg	3.2	3.3	3.5	3.8	4.0	4.3	5.0	7.2	12.0	17.9	24.8
	over 7 kg - 10 kg	2.2	2.2	2.3	2.5	2.7	2.9	3.3	4.8	8.0	12.0	16.6
	over 5 kg - 7 kg	1.5	1.5	1.6	1.8	1.9	2.0	2.3	3.3	5.6	8.4	11.6
	over 3 kg - 5 kg	1.1	1.1	1.2	1.3	1.3	1.4	1.7	2.4	4.0	6.0	8.3
	1 kg - 3 kg	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.4	2.4	3.6	5.0

Table 2: Lifting area factor. If the lift is performed outside the shaded area in the figure, add 1 point to the value of the closest cell.



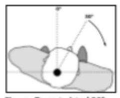


Figure: Torso twisted 30°.

Table 3: Calculation of Risk score.

	Factor	Possible worst case Factor
Frequency-and-weight factor from Table 1.		
Lifting area factor from Table 2.		
Do the following factors occur in the majority of lifts? If no, insert the value 1.0 to the right, else the stated value:		
☐ Lift with one hand. If yes, insert the factor 1.7.		
☐ Torso twisted more than 30° (see the figure to the right above). If yes, insert the factor 1.3.		
☐ Poor grip. If yes, insert the factor 1.1.		
☐ Hot environment 27-32°. If yes, insert the factor 1.1.		
☐ Two people lift the load. If yes, insert the factor 0.6.		
Risk score (multiply the factors in each column)		

Comment:

Score	Colour
≥ 5	
3- 4,9	
< 3	

Risk score 1:
Risk score 2:

5

4. Pushing and pulling work

Fill in the corresponding score in the white box **Score:**

If no pushing and pulling work occurs: Write 0 in the box on the right and go to 5. **No pushing and pulling work** 0

Make an assessment for an average case. Frequent handling of light loads (exerted forces < 50 N) is covered in other parts of RAMP II.

If the load is pushed or pulled for less than 5 seconds, only assess the initial force (the force to set an object in motion, sometimes called starting force) using Table 4. If it is pushed or pulled for 5 seconds or longer, assess <u>both</u> the initial and the continuous force (i.e. also Table 5).
1. Measure the exerted force.
2. Enter Table 4/Table 5 at the relevant frequency and force level to find the corresponding Frequency-and-force factor.
3. Calculate the Risk score in Table 6 by:
   a. inserting the values from Table 4 and when applicable from Table 5 into Table 6.
   b. assessing the other factors on the list in Table 6 and use these when calculating the Risk score in Table 6.
   c. multiplying the factors in the column for initial force with each other. Do the same for continuoius force if also such an analysis is carried out.
4. Insert the Risk score for the initial force, or if also continuous force is assessed, the highest Risk score of these two as "Risk score 1".
5. If single pushing and pulling tasks which are perceived as particularly strenuous occur, these should be assessed separately. If so, do the same for that case of those cases, i.e. perform step 1-3.
6. If one or two worst cases (initial and continuous force) are analysed insert the highest of these two Risk scores in the box "Risk score 2". Else, insert the Risk score from "Risk score 1" also in the box for "Risk score 2". Beside it information about if the Risk score corresponds to green, yellow or red risk level is displayed.

Table 4: Frequency and force factor for initial force (starting force).

Times per day	≤ 1	2 - 16	17 - 96	97 - 240	241-480	481-1920
Times per hour		≤ 2	2.1 - 12	13 - 30	31 - 60	61 - 240
Force value						
501 - 600 N	8.5	10	10.5	14	14.5	24
451 - 500 N	7.5	9	9.5	12.5	13	22
401 - 450 N	6.5	8	8.5	11	11.5	20
351 - 400 N	6	7	7.5	9.5	10	18
301 - 350 N	5	6	6,5	8	8,5	16
251 - 300 N	4	5	5	5	7	14
201 - 250 N	3	4	4	4	5	12
151 - 200 N	2.5	2.5	3	3	4	5
101 - 150 N	2	2	2.5	2.5	3	4
51 - 100 N	1.5	1.5	2	2	2.5	2.5

Figure: Pushing and pulling work.

Table 5: Frequency and force factor for continuous force.

Up to 8 meters: Use the force values in the table.
9 -30 meters: Add 50 N to the measured force to calculate the force value.
31-60 meters: Add 100 N to the measured force to calculate the force value.

Times per day	≤ 1	2 - 16	17 - 96	97 - 240	241-480	481-1920
Times per hour	hour	≤ 2	2.1 - 12	13 - 30	31 - 60	61 - 240
Force value						
501 - 600 N	10.5	12	12.5	17	19	30
451 - 500 N	9.5	11	11.5	15.5	17.5	28
401 - 450 N	8.5	10	10.5	14	16	26
351 - 400 N	7.5	9	9.5	12.5	14.5	24
301 - 350 N	6.5	8	8.5	11	13	22
251 - 300 N	6	7	7.5	9.5	11.5	20
201 - 250 N	5	6	6.5	8	10	18
151 - 200 N	4	5	5	5	8.5	16
101 - 150 N	3	4	4	4	5	14
51 - 100 N	2.5	2.5	2.5	3	4	12

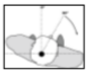


Figure: Torso twisted 30°.

Table 6: Calculation of Risk score.

	Factor Initial force	Factor Conti-nuous force	If any, worst case Factor Initial force	If any, worst case Factor Conti-nuous force
Frequency and force factor from Table 4, and, if applicable, from Table 5.				
Do the following factors occur <u>in the majority</u> of the pushes and pulls? If no, insert the value 1 to the right, else the stated value:				
☐ Pushing/pulling with one hand or sideways. If yes, insert the factor 1.7.				
☐ Gripping height: If the gripping height is below knee height or above shoulder height, insert the factor 2; if the gripping height deviates considerably from elbow height, insert the factor 1.2.				
☐ Torso twisted more than 30° (see the figure to the right above). If yes, insert the factor 1.3.				
☐ Poor grip. If yes, insert the factor 1.1.				
☐ Hot environment 27-32°. If yes, insert the factor 1.1.				
☐ Pushing/pulling work on slippery surface. If yes, insert the factor 1.7.				
☐ Two people perform the pushing/pulling. If yes, insert the factor 0.6.				
Risk score (multiply the factors in each column)				

Comment:

Score	Colour
≥ 5	
3- 4,9	
< 3	

Risk score 1:
Risk score 2:

6

5. Influencing factors

Fill in the corresponding score in the white box **Score:** **Comment:**

5.1 Influencing physical factors hand/arm - do the following occur? The times refer to "per work day".

	Yes	No	
a. The employee is exposed to hand-arm vibrations more than 20 minutes (10 for strongly vib).	2	0	
b. The employee is exposed to hand-arm vibrations more than 90 minutes (60 for strongly vib).†	4	x	
c. Warm or cold objects are handled manually.	2	0	
d. The hand is used as an impact tool often or a long time*.	2	0	
e. Holding hand tools weighing more than 2.3 kg for more than 30 minutes .	2	0	
f. Holding precision tools weighing more than 0.4 kg for more than 30 minutes.	2	0	

5.2 Other physical factors - do the following occur? The times refer to "per work day"

	Yes	No	
a. The employee is exposed to whole-body vibrations more than 1 hour.	2	0	
b. The employee is exposed to whole-body vibrations more than 6 hours.†	4	x	
c. The visual conditions are insufficient for the task.	2	0	
d. The work is carried out in hot or cold temperatures or in draughty environments.	2	0	
e. Standing or walking on a hard surface more than half of the work day.	2	0	
f. Prolonged sedentary work without possibility to change to do the work standing up.	2	0	
g. Prolonged standing work without possibility to change to do the work sitting down.	2	0	
h. Kneeling/squatting more than 30 times or more than 30 minutes.	2	0	

5.3 Work organisational and psychosocial factors - do the following occur?

	Yes	No	
a. There is no possibility to influence at what pace the work is performed.	2	0	
b. There is no possibility to influence the work setting or how the work shall be carried out.	2	0	
c. It is often difficult to keep up with the work tasks	2	0	
d. The employees often work rapidly in order to be able to take a longer break.	2	0	

† If you want to answer "No" on 5.1b or 5.2b, enter an "x" in the white answering box to the right.
*** Here "often" means about 100 times per working day or more and "a long time" about 30 minutes per work day or more.**

6. Reports on physically strenuous work

6.1 Documented reporting on physically strenuous work

Do documented reports exist of physically strenuous tasks (e.g. incident reports) when cayrrying out the work task?

	Yes	No	
Documented reporting	2	0	

6.2 Type of work that has led to reporting

If "Yes" on 6.1, mark (with an x) in the table below what type of work that has led to this. Else, go to 7.

lifting	
holding/carrying	
pushing/pulling	
pushing with hand or fingers	
other (please note)_______	

7. Perceived physical discomfort

Preferably ask five people who perform this work task.

7.1 Perceived physical discomfort

Are there parts of the work which lead to physical discomfort (e.g. in muscles or joints) during the work day?
Answer "Yes" if any employee experiences such discomfort.

	Yes	No	
Discomfort in muscles or joints	2	0	

7.2 If "Yes" on 7.1, which is the worst task?

Preferably state answers from five employees in the table below.

Person 1:_______
Person 2:_______
Person 3:_______
Person 4:_______
Person 5:_______

Comment:

K

Appendix - JSI

Strain Index Scoring Sheet

Date:		Task:	
Company:		Supervisor:	
Dept:		Evaluator:	

Risk Factor	Rating Criterion	Observation	Observation: Left	Observation: Right	Multiplier	Left	Right
Intensity of Exertion (Borg Scale - BS)	Light	Barely noticeable or relaxed effort (BS: 0-2)			1		
	Somewhat Hard	Noticeable or definite effort (BS: 3)			3		
	Hard	Obvious effort; Unchanged facial expression (BS: 4-5)			6		
	Very Hard	Substantial effort; Changes expression (BS: 6-7)			9		
	Near Maximal	Uses shoulder or trunk for force (BS: 8-10)			13		
Duration of Exertion (% of Cycle)	< 10%	**Calculated Duration of Exertion** (from inputs below)			0.5		
	10-29%	**User Inputs**	**Left**	**Right**	1.0		
	30-49%	Total observation time (sec.)			1.5		
	50-79%	Single exertion time (sec.)			2.0		
	≥ 80%	Number of exertions during observation time			3.0		
		Calculated Duration of Exertion (%)					
Efforts Per Minute	< 4	**Calculated Efforts Per Minute** (from inputs above)			0.5		
	4 - 8		**Left**	**Right**	1.0		
	9 - 14				1.5		
	15 - 19				2.0		
	≥ 20				3.0		
Hand/Wrist Posture	Very Good	Perfectly Neutral			1.0		
	Good	Near Neutral			1.0		
	Fair	Non-Neutral			1.5		
	Bad	Marked Deviation			2.0		
	Very Bad	Near Extreme			3.0		
Speed of Work	Very Slow	Extremely relaxed pace			1.0		
	Slow	Taking one's own time			1.0		
	Fair	Normal speed of motion			1.0		
	Fast	Rushed, but able to keep up			1.5		
	Very Fast	Rushed and barely/unable to keep up			2.0		
Duration of Task Per Day (hours)	<1				0.25		
	1 < 2				0.50		
	2 < 4				0.75		
	4 ≤ 8				1.00		
	> 8				1.50		
Results Key		SI ≤ 3	Job is probably safe				
		3 < SI < 7	Job may place individual at increased risk for distal upper extremity disorders				
		7 ≤ SI	Job is probably hazardous				

Notes/ Comments

Reference: Moore, JS and Garg, A. (1995). The Strain Index: A proposed method to analyse jobs for risk of distal upper extremity disorders. Journal of the American Industrial Hygiene Association, (56), 457-458.

Question? The Ergonomics Center of North Carolina
3701 Neil Street, Raleigh, NC 27607 1-800-ON-4-ERGO
www.TheErgonomicsCenter.com

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Appendix - SARA

Ergonomiutvärdering, del av SARA

Utfärdare:	Cykeltid: sek	Datum:	Belastade kroppsdelar/ sammanfattning:
Avdelning:	Arbetsstation nr:	Rotationsintervall: tim	
Beskrivning av arbetsuppgift:			

Utvärderingspunkter	Förekomst >5 sek	Kraft N/ Vikt Kg	Del av cykeltid el. del av tim el. rep/tim	Sum Poäng	Kommentarer
A-Arbetsställningar					
1 Knästående, huksittande eller stående på ett ben. Liggande eller halvliggande arbetsställning	Nej = 0 Ja = 4	2 - 4.5 kg = 1 >4.5-6.8 kg = 2 >6.8 kg = 3		0	
2 Framåtböjning mer än 30° i rygg eller bakåtböjd arbetsställning	Nej = 0 Ja = 2	1 - 4.5 kg = 1 >4.5-7kg = 2 >7 kg = 3	10-30%= 1 >30-60%= 2 >60% = 3	1	
3 Sidoböjning av rygg > 20° eller vriden >30°	Nej = 0 Ja = 2			1	
4 Nacken är fr.böjd eller vriden mer än 30 °eller är bakåtböjd	Nej = 0 Ja = 3	< 1 kg = 1 1 -4.5 kg = 2 >4.5 kg = 3	5-150/tim = 1 151-300/tim = 2 >300/tim = 3	0	
5 Arbete med händer utanför boxen	Nej = 0 Ja = 3	1 - 4.5 kg = 1 >4.5-7 kg = 2 >7 kg = 3		3	
6 Överarmslyft mer än 45°	Nej = 0 Ja = 2	< 1 kg = 1 1 -4.5 kg = 2 > 4.5 kg = 3		4	
Utvärdering del A: 0 - 7 Grönt >7 Gul	Färg del A	Gul	Sum del A	9	
B-Hand Arm					
7 Handled i icke neutral position	Nej = 0 Ja = 2	< 1 kg = 1 1 -4.5 kg = 2 > 4.5 kg = 3	5-150/tim = 1 151-300/tim = 2 >300/tim = 3 eller 10-30% = 1 30-60% = 2 >60% = 3	0	
8 Repetitioner/ min med hand el. underarm (trycka, dra, vrida, slag) Antal rep.	<45 N = 1 45-89 N = 2 90-180 N =6 > 180 N = 8			0	
9 Repetitioner/min med finger (trycka, dra, klämma, äntra) Antal rep.	<10 N = 1 10-44 N = 2 45-90 N = 6 > 90 N = 8			0	

10	Detaljen/Objektet som hanteras måste vändas manuellt Gäller om storleken på objekt >2000 mm (höjd+bredd+längd) 	Nej = 0 Ja = 2	1 - 4.5 kg = 1 > 4.5-7 kg = 2 > 7 kg = 3	10-30% = 1 30-60% = 2 >60% = 3	3	
11	Grepp < 0,6 eller >7 cm. Eller Vass kanter, hala/heta ytor  	Nej = 0 Ja = 2	1 - 4.5 kg = 1 > 4.5-7 kg = 2 > 7 kg = 3		0	
	Utvärdering del B: 0 - 7 Grönt >7 Gul	Färg del B	Grön	Sum del B	3	
C-Lyft						
12	Lyfta med två händer ____kg x avstånd (H) i m x 10 = _____Nm <1 lyft/min : >75 Nm 1 - 3 lyft/min >35 Nm >3 - 6 lyft/min: >25Nm >6 - 9 lyft/min: > 15 Nm >9 - 10 lyft/min: > 10 Nm 	Nej = 0 Ja = 4	Vikt obalancerad, halt eller dåligt grepp, ojämt underlag = 3		0	
13	Förekommer enhandslyft; överhandsgrepp > 0,5 kg eller underhandsgrepp > 5 kg eller övrigt grepp > 2kg?  	Nej = 0 Ja = 2		5-150/tim = 1 151-300/tim = 2 >300/tim = 3	4	
	Utvärdering del C: 0 - 3 Grön >3 Gul	Färg del C	Gul	Sum del C	4	
D-Energi						
14	Trycka eller dra med hela kroppen > 150 N 	Nej = 0 Ja = 3		5-150/tim = 1 151-300/tim = 2 >300/tim = 3	0	
15	Antal steg per minut	1 - 10 steg/min = 0 11 - 40 steg/min = 2 > 40 steg/min = 3			0	
16	Rotationsintervall vid ensidigt upprepat arbete	≤0,5tim = 0, >0,5- 1tim= 1, >1- 4tim= 2, >4- 8tim= 3, >8h =4			1	
17	Åtdragningsmoment handmaskiner, luftdrivna El.maskin vinkel + 10 Nm Elmaskin pistol +2Nm	Vinkelmaskin < 10 Nm = 0 10-40 Nm = 1 > 40 Nm = 3	Pistolmaskin < 2 Nm = 0 2 - 6 Nm = 1 > 6 Nm = 3	5 -150/tim = 1 151-300/tim = 2 > 300/tim = 3	0	
	Utvärdering del D: 0 - 3 Grön >3 Gul	Färg del D	Grön	Sum del D	1	
	Summa totalt A- D: Utvärdering: 0 - 16 Grön >16 Gul		Gul	Sum A - D	17	Kommentarer:
	Om någon del (A - D) ovan är Gul blir den total utvärderingen Gul och kräver vidare ananlys		Färg:	Gul		

M

Appendix - Comparison matrix

Benchmarking of Evaluation Methods		Ergonomic evaluation methods (Posture)											Organizations' standards			
		REBA	RULA	OWAS	EAWS	*NIOSH*	KIM I	KIM II	KIM III	HARM	RAMP II	JSI	SARA	VCS	GEELY	IPS
Neck:	Position	•	•						•	•	•		•	•		•
	Bend	•	•						•	•	•		•	•		•
	Forward head posture									•						
	Twist	•	•						•	•	•		•	•		•
Trunk:	Position	•	•	•	•		•	•	•		•		•	•		•
	Bend	•	•	•	•			•	•		•		•		•	•
	Twist	•	•	•	•	•	•	•	•		•			•	•	•
	Support				•										•	
Legs:	Bend	•		•	•		•	•								•
	Both feet	•	•	•									•			
	Feetdist (Inclines)							•			•			•	•	•
	Sitting			•	•				•					•	•	
	Squatting				•		•	•					•	•	•	•
	Kneeling			•	•		•	•					•	•	•	•
	Support				•				•							
	Walking			•	•				•						•	
Upper arm:	Position	•	•	•	•		•		•	•	•		•	•	•	•
	Abduction	•	•		•				•	•	•		•	•		•
	Raised shoulder	•	•							•						•
	Support	•	•		•					•						
Lower arm:	Extension	•	•		•				•	•	•			•	•	•
	Flexion	•	•		•				•	•	•			•	•	•
	Crossed arms		•													•
	Support								•							
	Out of side of body		•				•		•		•		•	•		•
Wrist:	Extension	•	•		•				•	•	•	•	•	•	•	•
	Flexion	•	•		•				•	•	•	•	•	•	•	•
	Radial deviation	•	•		•				•	•	•	•			•	•
	Ulnar deviation	•	•		•				•	•	•	•			•	•
	Supination	•	•		•				•	•						•
	Pronation	•	•		•				•	•						•
Hands	Coupling	•			•	•			•	•	•		•	•		
	Finger forces				•				•	•			•	•		
Muscle use:	Repetative	•	•		•	•	•	•	•	•	•	•	•	•	•	
	Exposure time				•	•	•	•	•	•	•	•	•		•	
	Rapid changes (Speed)	•						•			•	•				
Force/load:	Weight	•	•	•	•	•	•	•		•	•		•	•	•	
	Distance				•	•	•	•					•		•	
Rating method:	Rating based on table	•	•		•										•	
	Sum of groups						•	•	•	•	•	•	•			
	Index per group			•												
Point system:	1 -> 4 (G/Y/R/DR)	•	•								•	•		•		
	0 -> +50 (G/Y/R)				•		•	•	•	•			•			
	0-200														•	
	1 -> 7			•												
External factors:	Environmental (Temperature, tools, facility etc.)				•		•	•	•	•	•			•	•	
	Organizational (Work rotation etc.)				•		•	•	•	•	•		•	•	•	

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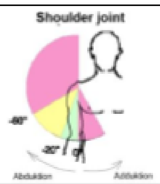
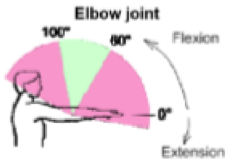
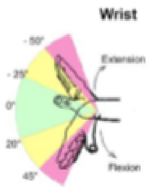
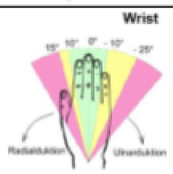
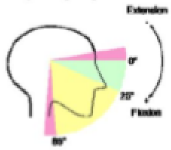
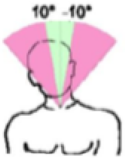
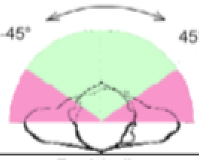
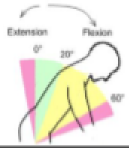
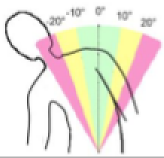
Appendix - Constraints and joint names

Constraints posed by KIM III (BauA [28]) and its corresponding IMMA joint(s) and rotational component(s).

Hand and arm constraints

Illustration of Angle	Limits proposed by BAuA	Corresponding IMMA joints and rotational component
	Green: 0° - 20° Yellow: 20° - 60^0 Red: >60° & <0°	Right GH.X + Right AC.X Left GH.X + Left AC.X
	Green: 0° - 20° Yellow: 20° - 60^0 Red: >60° & <0°	Right GH.Y + Right AC.Y Left GH.Y + Left AC.Y
	Green: 60° - 100° Yellow: --- Red: >100° & <60°	Right Elbow.X Left Elbow.X
	Green: -20° - 20° Yellow: -25° - -50^0 & 20° - 45° Red: >45° & < -50°	Right Wrist.X Left Wrist.X
	Green: -10° - 10° Yellow: 10° - 15^0 & -10° - -25° Red: >15° & < -25°	Right Wrist.Y Left Wrist.Y

Body posture constraints

Illustration of Angle	Limits proposed by BAuA	Corresponding IMMA joints and rotational component
Head incline 	**Green:** 0° - 25° **Yellow:** 25° - 85° **Red:** >85° & <0°	AtlantoAxial.Y
Head incline to the side 	**Green:** -10° - 10° **Yellow:** --- **Red:** >10° & <-10°	AtlantoAxial.Z
Head rotation 	**Green:** -45° - 45° **Yellow:** --- **Red:** >45° & <-45°	AtlantoAxial.X
Trunk incline 	**Green:** 0° - 20° **Yellow:** 20° - 60° **Red:** >60° & < 0°	T1T2.Y + T6T7.Y + L3L4.Y + L5S1.Y
Trunk incline to the side 	**Green:** -10° - 10° **Yellow:** 10° - 25° & -10° - -20° **Red:** >20° & < -20°	T1T2.X + T6T7.X + L3L4.X + L5S1.X

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Appendix - Guidelines for KIM III function in IPS

GUIDE FOR USE OF THE FOLLOWING METHOD IN IPS IMMA:

ERGONOMIC ASSESSMENT: KIM III

KEY INDICATOR METHOD 3

Document last updated: *2020-04-09.*

Scope of KIM III

KIM III is an ergonomic assessment method used to evaluate the ergonomic risks associated to physical workload in a situation. The method has now been converted to be used digitally through IPS IMMA. For more information about the KIM III assessment method, please click here to visit the official KIM III website.

Purpose

The purpose of this file is to help the user by working as a guideline in how to perform and interpret a KIM III evaluation in IPS IMMA.

Table of Contents

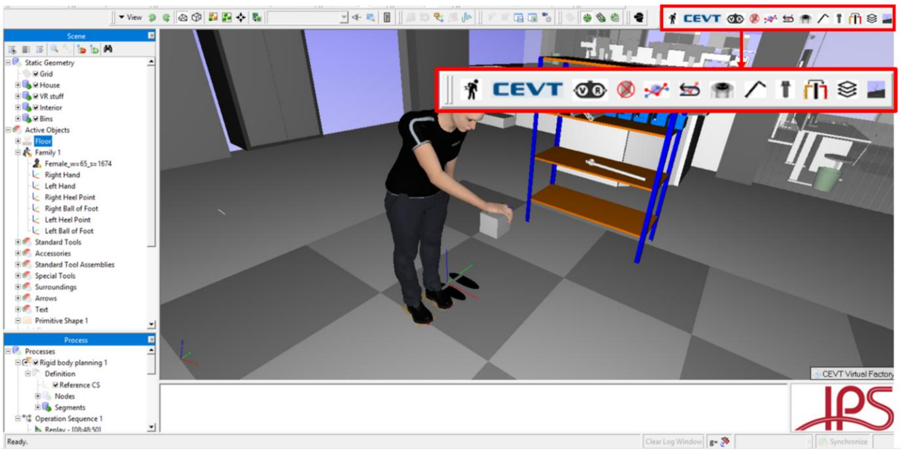
1. Setting up the assessment

The following bullets are the prerequisites for running the KIM III IPS functionality:

- Create a scene/scenario in IPS.
- Import one manikin family with one or more manikins.
- Position the manikin family in the desired position to be evaluated.

Step 1: Calling the ergonomic assessment function

- **Identify the CEVT functions in IPS**, located in the toolbar above the scene window. See red markings in the figure below.

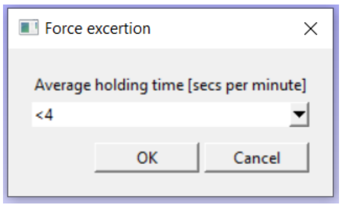


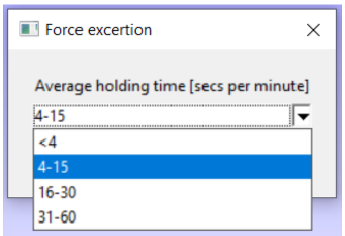
- **Press the ergonomic-assessment button**, represented by the following symbol:

Step 2: Answering questions in IPS

Once running the functionality within IPS the user will be exposed to 8 pop-up questions. The questions are directly taken from the KIM III template and will influence the total assessment score accordingly.

The pop-up questions are presented in dialog boxes to the user and will provide a series of predefined options from a drop-down list.





The following section will explain each question in more detail giving examples on how to answer them correctly:

Note! *All questions need to be answered in order to complete a full KIM III Method. When information and insight is insufficient use estimations and engineering intuition to best degree.*

- **Examples and guidelines** on how to answer the questions can be found at the end of this document.

2. Analysing the results

In order to analyze the results of a KIM III report, an assessment must be completely done. If not, go back to chapter "*1. Setting up an assessment*" and complete the tasks.

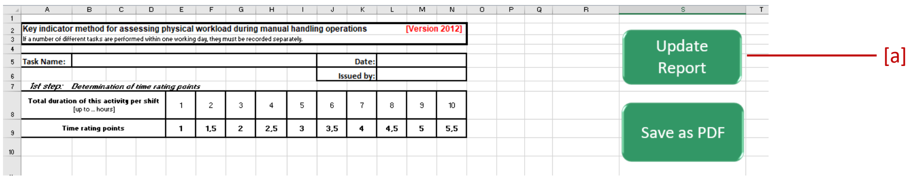
Step 1: Opening the report

- Once a KIM III method has been completely done, an Excel sheet of the report should be opened **automatically**.

Step 2: Updating the report

- When the KIM III report sheet has been opened, the information could be added by pressing the **"Update Report"**-button. This button is visualized in the figure as **[a]**.

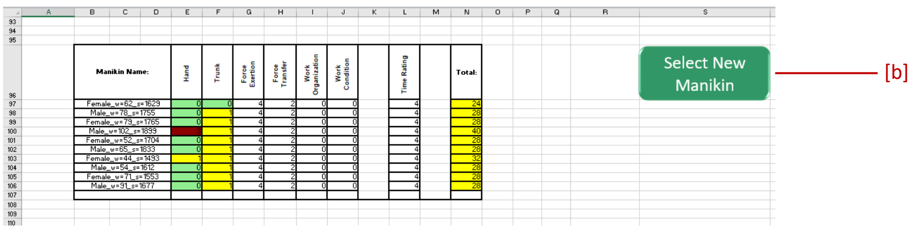
- Once the "**Update Report**"-button is pressed, the data should automatically be updated to the sheet.



Step 3: Changing manikin

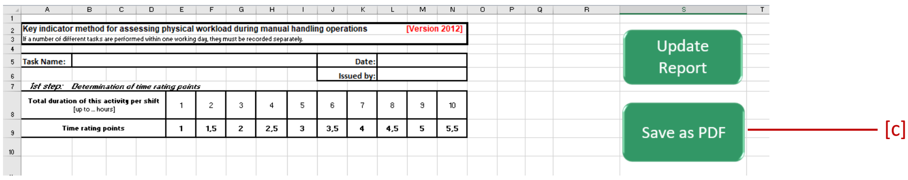
- Sometimes it is beneficial to evaluate multiple manikins in a family. This could be done by a function that lets you switch the data from one manikin to another in that specific family. The process should be done accordingly:

    - **Select the manikin** that you want to switch to from the table at the bottom. The manikin is selected by **pressing the cell containing the desired manikin's name**.
    -
    - **Press the "Change manikin"-button,** marked with a **[b]** in the figure below, to update the values in the report to the selected manikin's.



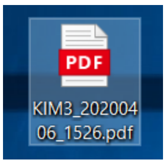
Step 4: Saving/Printing the report

- When saving the report, one should **always (!!!)** save the file by pressing the "**Save as PDF"**-button, marked as **[c]** in the figure below.



- Once the button is pressed, a popup window should automatically be presented with the current status of the print: "**Publishing…" / "PDF file has been created".**

- The user will get to select file name and location of the saved pdf-file.
    - The **default file name** will be: KIM3_XXXXXXXX_XXXX (where X stands for date and time of saved object). An example of the default file name is presented in the figure below.

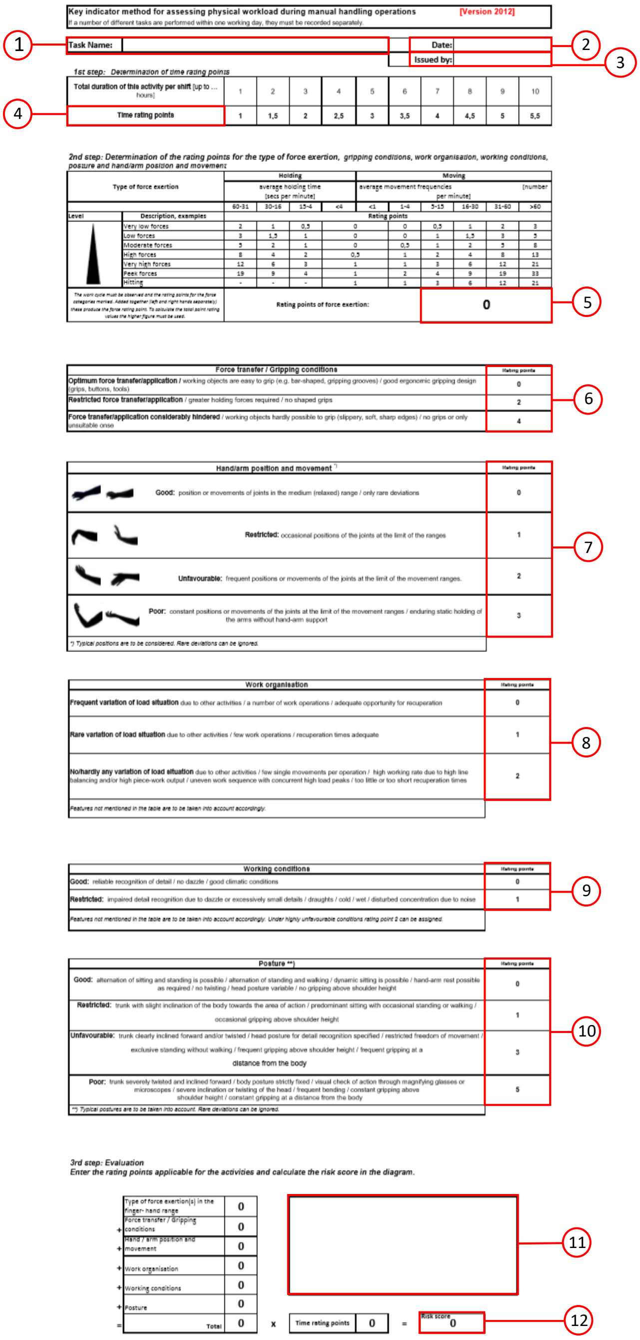


Step 5: Interpreting the report

- The KIM III report sheet is presented below with its including descriptions, see next page.

KIM III report sheet

1. Automatically updates the task name with the IPS scene name if one is available.
2. Automatically inserts todays date.
3. Automatically enters the CEVT user ID of the computer.
4. The result of question 1 will be displayed here.
5. A calculated value based on question 2, 3 and 4, will be displayed here.
6. The result of question 5 will be displayed here.
7. A score will be given based on the manikin's arms and hands position.
8. The result of question 6 will be displayed here.
9. The result of question 7 will be displayed here.
10. A score will be given based on the manikin's body posture.
11. A snapshot of the IPS window will be visible here.
12. The total risk score will give an overall score of the load situation based on all criteria's above.



Grading clarifications

- The results of the KIM III evaluation get presented through the following grading scheme:

Risk range ***)	Risk score	Description
1	<10	Low load situation, health risk from physical overload is unlikely to appear.
2	10 to <25	Moderate load situation, physical overload is possible for less resilient persons. For this group redesign of workplace is helpful.
3	25 to <50	Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.
4	>50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.

- The different risk scores and their correlating descriptions are presented in the report, according to the above shown figure. Recommendations are also presented in the description.

- In the report, the resulted risk score gets circled by a green, yellow or red box. In the figure below, an example of the risk score presentation is shown.

Risk range ***)	Risk score	Description
1	<10	Low load situation, health risk from physical overload is unlikely to appear.
2	10 to <25	Moderate load situation, physical overload is possible for less resilient persons. For this group redesign of workplace is helpful.
3	25 to <50	Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.
4	>50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.

Questions and guidelines

Question 1: *Total duration of this activity per shift [up to… hours]*

The total duration of the activity per shift is obtained from the duration and frequency of the work cycles analysed per shift.

Example: The work cycle under analysis consists of inserting a part in a machine and lasts in each case 6 seconds. This cycle is repeated 3000 times per shift. This means a total duration for the activity per shift of 3000 x 6 s = 5 hours.

Question 2: What type of task is it? (Moving / Holding)

Is it a static holding task such as supporting a carrying a part, or is it a dynamic moving task such as assembling parts?

Question 3: *Average holding time [secs per minute] /*
Average movement frequencies [number per minute]

The duration/frequency of the individual actions is recorded by analysing several work cycles. A work cycle is taken to be a cohesive time phase in which a work process takes place. This may be a few seconds (e.g. inserting a part in a machine) or several minutes (e.g. complete assembly of a product). It is important that representative values are identified by counting and measuring time. Experience shows that for cycle times of up to 60 s an analysis of 5 to 10 cycles is sufficient. For larger cycle times 10 to 15 cycles have to be analysed. The total frequencies counted or total durations measured are then to be divided by the number of minutes observed. From this it is possible to calculate the average holding times and average movement frequencies.

Question 4: *What kind of force is exerted?*

Very low forces: e.g. button actuation / shifting / ordering
Low forces: e.g. material guidance / insertion
Moderate forces: e.g. gripping / joining small work pieces by hand or with small tools
High forces: e.g. turning / winding / packaging / grasping / holding or joining parts / pressing in / cutting/ Working with small powered hand tools
Very high forces: e.g. cutting involving major element of force / working with small staple guns / moving or holding parts or tools
Peak forces: e.g. tightening, loosening bolts / separating / pressing in
Hitting with ball of the thumb, palm of the hand or fist

Question 5: *How good is the force transfer/gripping conditions?*

The indicator "force transfer/ gripping conditions" covers the type of force transfer and additional forces. The following are important here:

- The relationship of the type of handle to the action force required
- The type of force transfer by way of positive form locking or traction
- The object surfaces

Question 6: *How often dose variation in load situation occur?*

The indicator of question 6 considers in particular the risk of excessive muscular fatigue due to:

- One-sided, identical load situation pattern
- High work rate
- Inadequate breaks

The prime question here is whether the load situations are very one-sided for the workers and only very restricted possibilities for recuperation exist, and whether a variation of the load situation, e.g. through different activities or long cycle times with differing requirements, occurs and body regions subject to load situations can recuperate.

Question 7: *How would you describe the working conditions?*

The indicator "working conditions" covers interfering factors in the performance of work. The points of reference here are:

- Restricted visual conditions
- Cold, draughts, wet
- Interfering noises.

Good: Reliable recognition of detail / no dazzle / good climatic conditions
Restricted: Impaired detail recognition due to dazzle or excessively small details / draughts / cold / wet / disturbed concentration due to noise.

Question 8: *Which hand is used in the activity?*

Please identify the most affected hand in the current work task or use the option to evaluate the manikin with both hands.

Left hand: Calculates a score based on the left hand/arm position.
Right hand: Calculates a score based on the right hand/arm position.
Both hand: Calculates a score based on both hands and arms position.

Document made by: Henrik Söderlund and Leonard Bogojevic, 2020.04.08.

For any further questions regarding this document or function, contact Anton Berce at anton.berce@cevt.se.