CHALMERS
UNIVERSITY OF TECHNOLOGY

Application of Human-Industrial Robot Collaboration

Prerequisites and benefits of HIRC

Master of Science Thesis in Production Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

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Cover: Conceptual model of the future state of the Inspection Station at GKN Aerospace Trollhättan.

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Abstract

To be able to stay competitive it is important to take advantage of new technology and research. Human-Industrial Robot Collaboration (HIRC) is a concept of a work task division between human and an industrial robot in a shared work space. It is only during the recent years that the idea of automation concepts that includes humans, have been realized, but with specialized small robots, cobots. In systems where an industrial robot traditionally is used there are usually rigorous safety systems consisting of fences to keep the human safe. However, for many tasks in the heavy industry the cobots are too weak and an industrial robot is needed. There are a lot of benefits with automated systems and therefore it is valuable to find a solution where the strengths of an industrial robot are mixed with the abilities of humans. In this project, the collaboration between a human and an industrial robot has been investigated.

For a HIRC it will be important to let the human do the task best suited for a human and a robot the tasks best suited for automation. Hence the first goal of this report, to create a check-list to use when deciding if HIRC could be used at a station. It was developed through literature studies and a case study performed at GKN Aerospace in Trollhättan. The check-list was used to find a suitable pilot station for evaluating HIRC. The conclusion after applying the list, was that an inspection station was a station where HIRC could be applied. HIRC at the inspection station could lead to several benefits since the robot could take over some tasks which would make the remaining work better from an ergonomic point of view and easier to understand for the operators. To let the operator focus on tasks that required human abilities and let the robot and automated system do other task could lead to higher efficiency, better quality and a more standardized work procedure.

Keywords: Human-Automation Interaction, Task division , Automation, Man machine, Standardized work

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Thanks also to all employees at GKN in Trollhättan who always answered e-mails quickly and took time for interviews and meetings. Without your support this thesis would not have been possible.

Julia Asplund, Josef Brile, Gothenburg, June 2017

List of Figures

List of Abbreviations

HIRC .... Human-Industrial Robot Collaboration
LoA .... Levels of Automation
GKN .... GKN Aerospace, the company where the case study took place
ROI .... Return on investment
REBA .... Rapid Entire Body Assessment
RULA .... Rapid Upper Limb Assessment
PDM .... Precedence Diagram Method
KPI .... Key Performance Indicator
IFR .... International Federation of Robotics
MABA-BABA Machines Are Better At, Men Are Better At
NIOSH .... National Institute for Occupational Safety and Health

Contents

1
Introduction

This chapter aims to introduce the reader to the subject of this report and why it was written. The introduction seeks to give a background of the thesis, why it was written and the purpose of the thesis. One research question is stated to help the authors to investigate and reach the two goals. Last in this chapter the delimitation of the project is stated.

1.1 Background

The Swedish government has calculated that 70% of all export from Sweden is due to the manufacturing industry which also is employing almost one fifth of Sweden's workforce [1]. The manufacturing industry is also an important stakeholders when it comes to science and research, and hence, a driving force for development of the society [2]. One issue that the Swedish manufacturing industry is facing right now is recruitment of employees. This is due to that the number of experienced workers retiring is much higher than the number of people, with the desired competence, entering the labor market [3]. The future workplaces need to be designed in a way that gives an equal opportunity to work and not only certain groups (for example people with a higher degree). This could mean that work tasks needs to be simplified. It could also mean designing workplaces in a way that makes it possible for people to work to a higher age.

To be able to stay competitive and maintain productions in Sweden, a high cost country, it is important that companies take care of advantages that research initiatives and newly developed technology can contribute to [4]. During the recent years, several so called *collaborative robots* has been launched to the market and also applied in the manufacturing industry. These robots are small, soft and have technology that makes them less likely to hurt humans. However, these robots have limitations in capacity and due to the force limitation they cannot lift more then 30kg[5]. Therefore, it is more interesting for several industries to investigate if it is possible to use industrial robots in a collaboration with humans. In systems where an industrial robot traditionally is used there are usually rigorous safety systems consisting of both fences and sensors that can stop the robot movement. In these kinds of systems, the robot performs some parts of the job while the operator is left with monitoring, loading/reloading and other tasks that are uneconomical or hard to automate.

In Sweden a research project with the title *Virtual Verification of Human-Robot Collaboration* has been started to investigate how industries in Sweden can benefit from human-industrial robot collaboration [6]. The objective of the project is the creation of a tool that facilitates efficient and valid simulation of human-robot collaboration. Also consideration of human variation is supported to improve ergonomics and work load balancing between robot and human. Companies included in the project are Fraunhoefer Chalmers centre, several companies from the vehicle industry and GKN Aerospace, that operates in a different business than the other companies in this project.

GKN Aerospace is the aerospace operation of GKN plc, serving a global customer base and operating in North America and Europe with sales of £2.2 billion in 2014. GKN in Trollhättan is a part of the Engine Systems department of GKN Aerospace. The products produced in the facility in Trollhättan are varied in function and size and most of them are hard to handle without equipment and tools. The products does also vary when it comes to what kind of operations will be needed and many of the products need processing from both robots and humans. The interest for GKN in HIRC is to investigate how the technology can lead to good ergonomics for the operators and at the same time make sure to keep the effectiveness in the production. However, as most other companies, GKN is operating in a global competitive setting and it is important for the company to understand what benefits can be seen from new technology before an investment can be made.

1.2 Purpose

The thesis work will contribute to the implementation of HIRC at GKN, identifying potential prerequisites and benefits for the technology. The aim is to find prerequisites for increasing the efficiency of the production and the ergonomics of the operator. To aid the fulfillment of the purpose a research question was stated:

What would be the prerequisites to consider when implementing HIRC and what benefits will the technology lead to?

Explanation of research question

- With prerequisites means functions of the station in current state, characteristics of work task, organization etc. that makes a station more suitable to HIRC then other production technologies such as manual work or traditional automation. The prerequisites also includes safety and regulations.

Two sub goals have been identified from the research question:

1. **Create a check-list for how to evaluate whether a HIRC application is suitable.**
2. **Choose a pilot station for HIRC at GKN.**

1.3 Delimitations and clarification of purpose

A new design of the pilot station will not be suggested in this report. A conceptual design, stating the most important functions of the station and a task division between human and robot will be included. The word *function* can be explained as: "the kind of action or activity proper to a person, thing, or institution; the purpose for which something is designed or exists; role" [7]. In this report the "functions" will describe how the HIRC needs to work to make the work place safe for the operator and more efficient then other production solutions.

Human friendly robots will not be considered as a solution, the robot in the conceptual design will be an industrial robot.

We will not consider whether the station best suited for HIRC was found at GKN but will investigate one station where HIRC is considered possible after a screening of a number of stations.

The focus will be on efficiency and cost since the research and technology department at GKN will need to make an investment proposal. However, several other aspects of improvements is discussed since e.g good ergonomics will lead to an efficient work place and lower cost for sick leave etc.

A future delimitation is that HIRC in this case mean that the robot and the human perform their tasks at the same time, in the same work space.

2 Research approach

A case study was performed at GKN. The case study included methods which are described in this chapter. How the literature study was done is described as well.

The reason for the interest from GKN with initiating the project was to get a first introduction to how HIRC could be used at the company, but also to raise interest and see what benefits the technology could result in. In addition to that there were also aims from the academia of Chalmers to contribute to the research of production engineering and therefore the methods and strategy used during the project will be presented here.

In figure 2.1, the methods used for each sub goal is presented and the chronological order is marked with arrows. The thesis started with stating the research question. To answer the research question, two sub goals were stated. A triangulation was performed, including the case study and the literature study, to fulfill the goals and answer the research question.

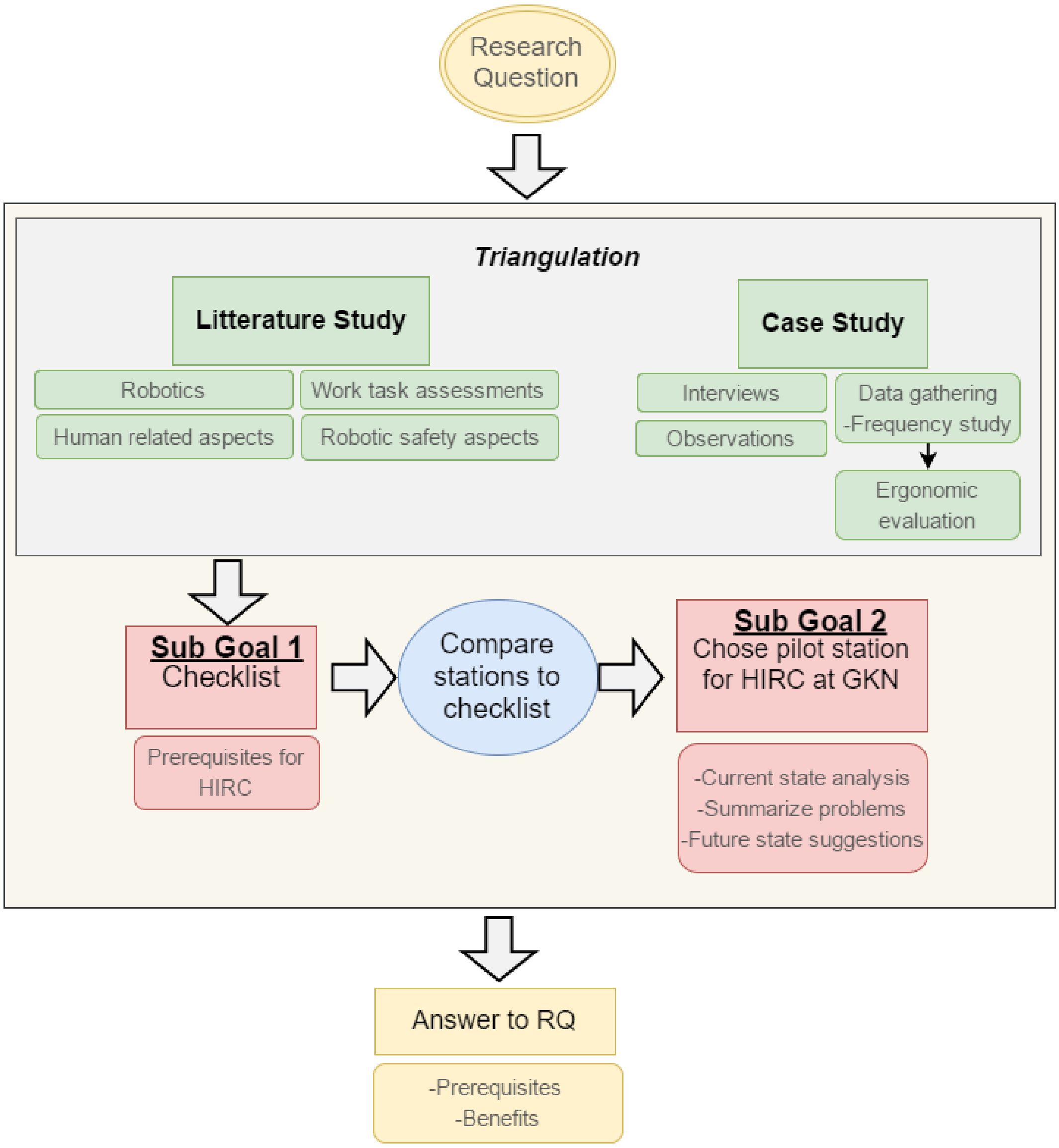

Figure 2.1: Research Approach

2.1 Triangulation

Triangulation is a widely used method and can be used in many ways [8]. The reason for triangulation is to base conclusions and gain facts from different sources. Triangulation is often used to strengthen results and investigate if, for example interviews with experts are showing the same things as the literature study is displaying.

One benefit of using triangulation is that information can be compared between the sources [9]. If many sources point in the same direction the information is more reliable. Vice versa, if the sources are deviating from each other, a deeper analysis can be necessary. A drawback with triangulation is that it is more time consuming to use several sources than one.

In this case triangulation was used with the different sources literature study and case study. These two sources gave individual results, that in this study helped with strengthening the overall result. Also, the two stakeholders of this thesis, the company and the university, and their requests to find results that could be used both by the industry and the academia led the approach of triangulation. Another kind of triangulation was done in the case study when information was gathered from many sources to understand the views from different stakeholders.

2.2 Literature Study

The purpose of the literature is to provide relevant knowledge to help answer the research question and reaching the goals of the thesis. The literature will also support with theories and facts that can be used to the analyse and discussion of the results [10]. To find prerequisites for HIRC in literature, a broad perspective had to be used when searching articles and other reliable sources. Many different areas were considered but the scoop was narrowed down to focus on the prerequisites that concerned the functions of the robotics, how to ascertain safety and health for the workers and how automation can increase efficiency. Another purpose of the literature study was to give the authors knowledge to conduct relevant interviews regarding the thesis subject.

Since one of the strong areas of Chalmers is production development it was considered defensible to use material from courses and teachers at Chalmers since the research at Chalmers can be considered to be in front edge [11]. To use some already familiar literature from Chalmers also gave the authors the opportunity to use already gained knowledge and that made it easier to start the project.

Other books and literature were conducted from the following databases that were used through the Chalmers library:

- Emerald library, emeraldinsight.com
- Dawsonera, dawsonera.com
- International Organization for Standardization, iso.org
- Taylor and Francis, tandfonline.com/
- Springer, https://link.springer.com/

The key words that are used in this research were the following:

- Development
- Industrial robot
- Automation
- Collaboration
- Collaborative
- Robotics
- Ergonomics
- Application
- Work task Devision
- Man Machine
- Logistics
- Layout
- Safety
- Standard
- Regulations

The variation of articles found in the additional literature search is considered broad since they are published in different countries and in different years. For articles describing technology, regulations standards etc it was considered important to have newly published articles to make sure the information was not outdated. However, for some articles it was considered to be the other way around, the information was chosen since it was old articles that was still cited frequently in newer research, examples here can be the references about task division.

For some more general information, that was not considered very technical, a search on www.google.com was used as a start to investigate how much information was available and what sources could be used. Search words for this approach were:

- Robot collaboration
- industry 4.0
- Sensors and safety systems for automation
- development of industrial robots
- Swedish industry
- Work law regulation

From this method, information from companies, the government and web pages specialized in a certain topic was found. It was considered important to also use theory not published on universities and similar institutions to gain an additional view on the investigated topic from important stakeholders from the surrounding society.

2.3 Case study

Since the project was done in collaboration with GKN aerospace, it was natural to do the investigations as a case study in the production of the company. Since no known applications of a HIRC where an industrial robot and human share work space has been found in the Swedish industry to state example, it was valuable to give a real example of how the technology could be used and thereof the pilot station.

In literature about case study as a research method the method is explained as a way to study something in its´ natural setting and to narrow down an issue to a level where it can be studied in a case [12]. There are both advantages and disadvantages of a case study and it is important to understand what conclusions can be drawn from such a narrow method. That the case study leads to results that are special for the unique case will give both pros and cons. The pros will be that the studied subject can be analyzed very deeply and exact [13]. The cons on the other hand will of course be that the results are not very general and could possibly be different if the case took place in another setting.

2.3.1 Validity and reliability in a case study

Validity is describing how good a study was and how valid the result can be [14]. Validity is also describing how well the methods answer to the purpose and research question/s of the project. To make sure a certain degree of validation has been met it is important to document delimitation and to make sure the question is objectively formulated. There are two types of validity, internal and external.

The internal validity is how good explanations of findings are, if the conclusions are reliable [15]. This is furthermost interesting when the researcher has made causal relationships between findings. To guarantee that causal relationships found in a case study are real, and that there is no other explanation to a finding, other sources such as theory references are often used.

The external validity is dealing with the issue if the findings and causal relationships can be generalized and used in other contexts than the one studied in the case study [15]. Especially when "single case design" have been used, only one studied case e.g. one company, it is important to discuss how and why the researchers think that these results can be used by others.

The reliability in a case study is a measurement on how big the chance is that the same results could be found by someone else by using the same method [15]. The reliability is describing if the same conclusions would have been found by another researcher conducting the same study. One part of the reliability is how well documented the methods and process are and another part is how specific the circumstances was when the case study took place. One way of increasing the reliability would be to, in the same way as for validity, use multiple sources to enhance results. Another way would be to increase the volume of gathered data to make sure biased data will not affect the results too much. This would for example mean to do several interviews, do observations on different days and times and for quantitative data gathering increase the number of "measure points".

To increase the validity and reliability of the case study done at GKN several methods have been used and will be described in the subsections below.

2.3.2 Observations

Since the authors were new to the company, observations of the production were performed. Observation is a good tool to use when, the actual tasks in a production can differ from both standards and self- explanations from the operators, when understanding the setting in a detailed way is important or when little is known to start with [16]. However, observations should not be the only source of information since the state of the observed area may change. In this case, the authors also found observations to be a less time-consuming way of gathering information to start with rather than interviewing all the stakeholders.
The observations were also performed to understand how the work tasks was carried out, how often and with what level of automation. The observations gave an un-

derstanding for tasks that seemed hard, heavy or dangerous. This gave important insights regarding the interviews performed in the project.

2.3.3 Interviews

In this project two types of interviews were performed, semi structured interviews and unstructured interviews. The semi-structured interviews was done with the operators and the unstructured was for White collars.

Semi-Structured Interviews
In a semi structured interview the interviewer has predetermined questions that should be asked but is also allowed to deviate from the questions, use follow up questions etc [17]. In a semi-structured interview the answers needs to be analysed to understand the meaning of them which can be time consuming.

The Semi-structured interviews are used to get qualitative knowledge and relevant information from each interviewee [18]. The flexibility of semi structured interviews gave the authors the opportunity to follow up on interesting answers and get information on subjects that are missed in the first interview template, appendix A. However, the authors thought it was very important to use a template as foundation for the interviews with the operator to give each operator the opportunity to give his/hers opinion on all matters that the authors found important.

Four operators were interviewed at the chosen pilot station, and two operators at each of the three other stations that were not chosen. The purpose of the interviews was to know what parts of the work that could be improved with HIRC. The aim was to investigate what problems to be found at the station from the operators point of view. The interview template can be found in appendix A and had one part with practical questions and one part with personal questions.

Unstructured interviews
The unstructured interviews were carried out as discussions based on questions that was specific for each interviewees area. This was considered the best method since standardized questions could not be used. These interviews were performed to get an understanding of prerequisites of HIRC, the company functions, to find a pilot station and to understand how GKN work with automation projects.

Many unstructured interviews were followed up with more interviews with other people, so called snowball sampling[19]. This method is good to use when the interviewer needs information but do not know where to find it, which were the case in this thesis. A drawback could be that persons who are interviewed can be biased and in some cases avoid to refer to the best person for the next interview. One benefit of unstructured interviews is that findings can be done that the interviewer had not thought about [20]. At the same time, the interview can also lead astray and valuable information can be lost. An unstructured interview is also very hard to replicate and analyse if it is not documented or recorded.

The white collar workers interviewed with this method were: first line managers, method-owners, technicians, employees at HR and employees at the economy department. The interviews aimed to capture the general attitude for HIRC at the company but also to take advantage of the knowledge from different fields e.g. lean and robot maintenance etc.

In addition, other stakeholders interviewed were representatives from companies that work with development and installations of industrial production systems. Questions for those representatives was focused on their experience of HIRC and what benefits and difficulties they saw with this technology. Costs and time estimation for implementation of HIRC were also discussed.

2.3.4 Data gathering

Data gathering was performed to get objective facts regarding work tasks and time distribution at the stations. Also, the gathered data was used to evaluate the ergonomics. The methods described in this section was performed on the pilot station. The document analysis aided the authors in the understanding on how the tasks should be performed compared to the observed implementation of the tasks.

Precedence diagram method (PDM)

A Precedence diagram was developed to understand what tasks were performed and as a way to organize the tasks and visualize them [21]. To use a precedence diagram as an analysis tool is a common method in task management [22]. The precedence diagram states the operation and the goal and can then be broken down in tasks with the given order showed as arrows between the tasks. The arrows in this report are also used to generate loops for tasks that are repeated. A finish to start relationship has been used to define the task sequence. This means that the next task will not be started until the preceding task is finished.

Frequency study
A frequency study was done to capture what different work tasks is done at the pilot station and how often each work task is done. A frequency study is a good tool to use to understand the distribution of each work task without monitoring the process with a stop watch [23]. The frequency is done by dividing the work in different tasks and then measure with regular, predetermined intervals. Since the frequency study is done as a statistical data gathering it is important to make sure the data is enough and that the confidence of the study is high enough. To calculate this the following equation in Figure 2.2 is used.

Work sampling theory

$$N = \frac{z^2 p(1-p)}{e^2}$$

N = Number of observations
p = Probability of a single occurrence
e = Acceptable limit of error

With 95% confidence interval z=1,96

$$N = \frac{1{,}96^2 p(1-p)}{e^2} \qquad e = \pm 1{,}96\sqrt{\frac{p(1-p)}{N}}$$

Figure 2.2: Formula for work sampling [23]

An alternative to a frequency study is a time study. However, for the pilot station investigated in this report a frequency study was the best option due to the long work cycles. The frequency study was also a good tool since the manual work at the pilot station led to a great variation in how the work was executed from day to day and operator to operator. A frequency study gave the authors the opportunity to collect good statistics without spending all the time that a time study would have required.

Ergonomic analysis
One of the factors to concern when it comes to operator well-being is ergonomics. Since a lot of research has been conducted on the topic of ergonomics there are several established ergonomic evaluation methods existing, as REBA(Rapid Entire Body Assessment) and RULA(Rapid Upper Body Assessment) mentioned in the theory[24]. Also, many companies has established their own requirements and standards. GKN is one of those companies that has established their own ergonomic specifications, mostly based on Swedish work law regulations, and these was used to evaluate the ergonomic at the stations in this project. Example on how these standards looks like at GKN can be seen in appendix B. To use the companies own standard instead of the general methods like RULA or REBA is good as long as the standard take into consideration the duration of the work and gives a clear result on whether the result is acceptable or not.

The GKN ergonomic standard was based on positions considered as "good", "bad" and "very bad" for the operator and according to the standard these positions could be used but not for to long. To understand if the time spend in bad positions was within requirements or not the inspection task was divided into "inspect, good ergonomics" and "inspect, bad ergonomics" in the frequency study.

Document analysis

To gather information from existing historical data is a good tool when data is available since it does not require much work from the investigator to analyse already existing data[25]. Even though data from several years back can exist such as, quality measurements, efficiency measurements etc, the analyser needs to be careful to not trust the data without considering reasons why the data is not trustworthy[18]. There are several motives and reasons to why data is not reported in the same way all the time and why numbers can be biased. Therefor historical data can be used to investigate trends and to understand what KPI´s that are important at certain stations but should be backed up with own objective findings.

3 Theory

This chapter covers facts and information about relevant areas for investigating in HIRC. The focus is on theory that can support and elaborate a Human-Industrial Robot Collaboration.

Since HIRC (Human - Industrial Robot Collaboration) is a new technology there is not much research performed on the subject[26]. Robots are generally placed in cages or places unreachable by human due to safety risks. One of the main goals with HIRC is to be able to have an industrial robot working close to a human without exposing the human to any risk.

3.1 Development and implementation of robotics

This section will describe how robotic development up until now and how the development will continue. Furthermore it will be described what will be considered for an implementation of robotics.

3.1.1 Development of robotics

Automation can be used in many applications but an automated system is a system that can overtake human tasks, they are being automated [27]. A definition found in a dictionary explaining the word automation says: "automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labour" [28]. The tasks can include, movements, applying of forces, precision work, sorting, decision making, data gathering etc. Since robots can do so many things there are many possibilities to be creative when it comes to robot implementation.

The International Federation of Robotics (IFR) [29] have investigated in the use of robotics of today and the potentials for robot use in the future. The robot industry is considered to have great potential to grow fast in the coming years due to new technical improvements and changes on the labour market. IFR have compiled the use of industrial robots in a graph based on the development of robot use per branch and the annual total sales of robotics from 1995 to 2013, see figure 3.1.

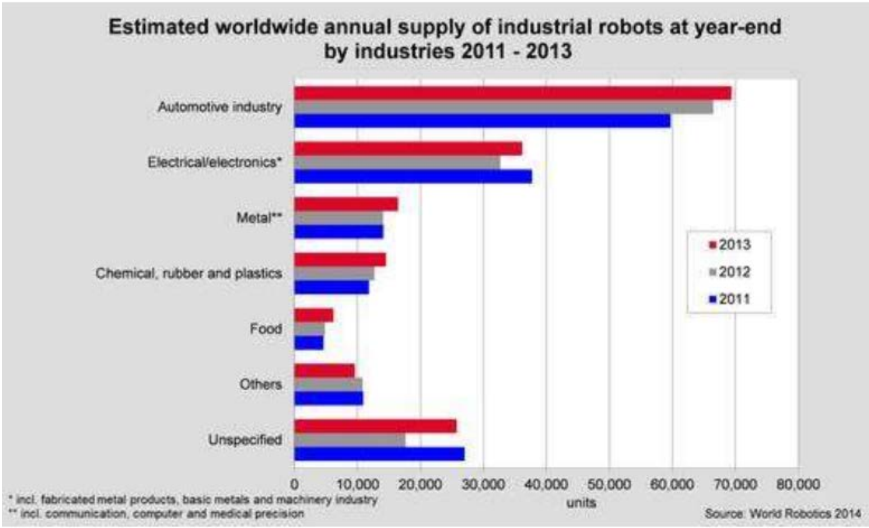

Figure 3.1: Industrial robot application areas

The automotive industry has led the implementation of robot systems as can be seen in Figure 3.1. Robots are used frequently in the vehicle industry where different variants and frequent introduction of new models require automation systems that is flexible and accurate [27]. There should though be said that for many vehicle producers there is still a large amount of manual work done especially in the final assembly where robot systems are mostly not flexible enough. The reason for the slower introduction of robotics in the final assembly is due to the higher complexity of the tasks there. Before the complexity, with many tasks carried out inside the car, made it impossible to automate some tasks. Nowadays the technology is usually able to handle most assembly situations but often not cheaper than a human or with a very long payback period [27].

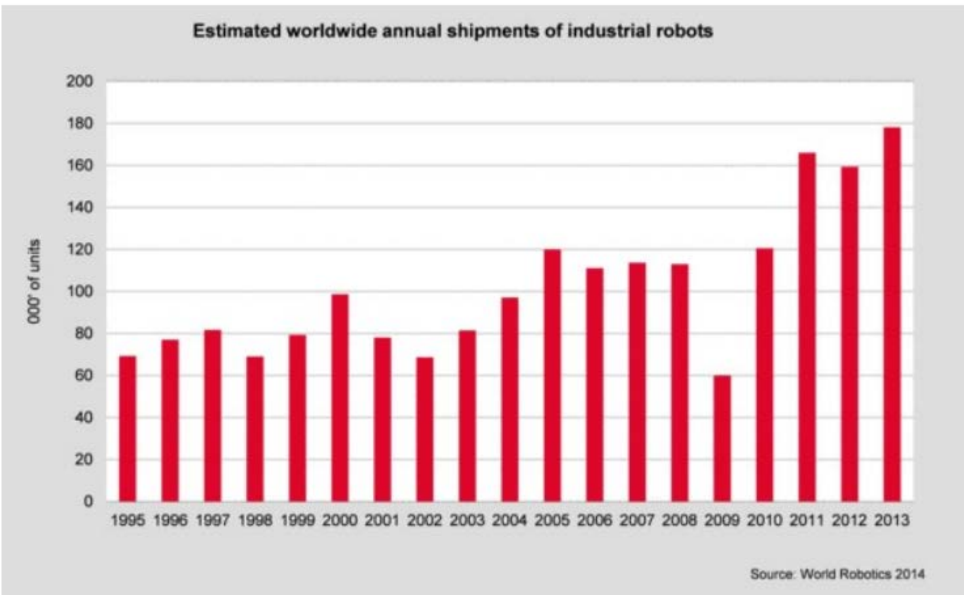

Figure 3.2: Estimated worldwide annual shipments of industrial robots

For other branches the implementation of automation is now starting to be more interesting when labour costs are rising in many countries [29]. With new technology, the prices for automation has decreased and that makes investments in robot system more attractive. When IFR is showing the usage of robotics in different industries in the world they draw the conclusion that there are huge potentials for other industries to invest in robotics at the same time as there are still room for robotics in many parts of the automotive industry.

Up until now the tasks the robots are doing and the tasks humans are doing have been very divided [30] [31]. Robots are often operating in the beginning of the production with welding, painting, or electronic assembly far away from the humans that are doing for example final assembly. The latest research in robotics do however have the wish to introduce a new generation of robotics in industrial production, the collaborative robotics. This is to find the optimal manufacturing solution for productions that have requirements that ends up in the middle of optimization through manual labour or optimization through automation. ABB presents the opportunity for collaborative robotics as in figure 3.3. In this graph, the collaborative robotics are described as the bridge between humans and robots suitable for a flexible production demanding high output.

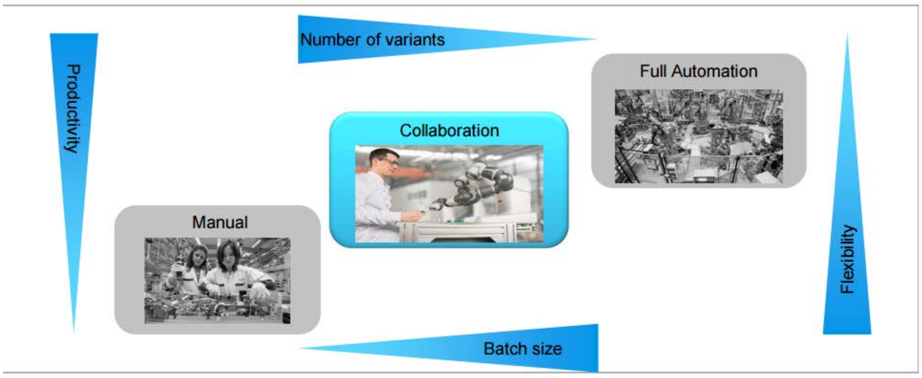

Figure 3.3: Manual, Collaboration and Full Automation

According to Kruger et.al [32] human-robot collaboration should be used where it is possible to take advantage of both the strengths of the human and the robot in the same workstation to increase the flexibility and efficiency. Benefits are gained especially when a robot can be guided by a human to increase flexibility and a robot can help the human with the additional power it holds.

There is often discussed that robotics will take the jobs from humans in the future [33]. Most likely this will not happen since implementation of robotics is mostly done to get rid of dangerous, “dirty” and/or physical demanding jobs. Implementation of a robot system often lead to changes of work tasks for the human to programming, technical maintenance, inspection etc. That kind of tasks are milder to humans and do usually lead to a more rewarding job situation, more education and higher wage [34].

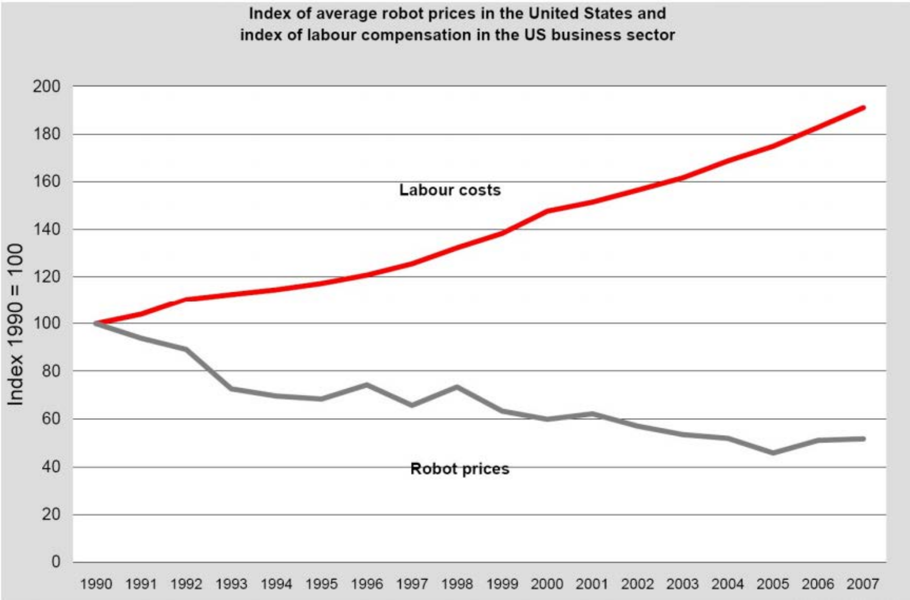

Figure 3.4: Labour costs and Robot prices

In the future, it will be more important for companies in all industries to develop the knowledge about automation and robotics to stay competitive [27]. One of the reasons is the higher educational level in many countries where the workforce requires higher qualifications on their jobs. Also, higher demands for health and safety is factors that will make robots more suitable to use in the future.

A successful implementation of a robot system is often based on experience from the project leaders[27]. To succeed the first time when implementing a robot system, a systematic and structured way of working is required.

3.1.2 Cost of robot implementation

To increase the level of automation from a manual state to a state where a robot is used will always lead to a purchase of a robot (unless the company has a stock of unused robots laying around) [27]. To justify the purchase of a robot and a redesign of a station the new solution needs to be seen as an investment. To justify an investment for the company certain calculations about payback time and yearly savings from the investment needs to be done, so called Return On Investment (ROI).

The ROI do often correspond to a payback time that needs to be considered from the management of the company. Companies usually have a standard payback time for when an investment needs to start creating value and if that payback period is not met then the management will not give the money requested for an investment. For larger investments, something that a robot and redesign of a station is often seen as, it will be the senior managers together with finance personnel that will take the final decision. It is therefore important to in a structured way analyse and organize information about the investment and the possible benefits. To give the management a foundation for decision making will require data that is reliable and often the most important data are data that can be converted into economical measurements.

The IFR has stated 10 benefits that is often seen when implementing robots and that could justify an investment [27]. These are:

1. Reduce operating costs
2. Improve product quality and consistency
3. Improve quality of work for employees
4. Increase production output
5. Increase product manufacturing flexibility
6. Reduce material waste and increase yield
7. Comply with safety rules and improve workplace health and safety
8. Reduce labour turnover and difficulty of recruiting workers
9. Reduce capital costs
10. Save space in high-value manufacturing areas

3.2 Work task assessments

This section includes theory about how to divide tasks between humans and machines, Levels of Automation (LoA), standardized work and iso standards for human-robot collaboration.

3.2.1 Task division

One of the first researchers studying the concept of human-machine interaction was Fitts [35]. He made a list called MABA-MABA (Machines are better at, Men are better at) and the list has since it published been the foundation for evaluation of how to divide human work and machine work.

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

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

Figure 3.5: Fitts List, MABA-MABA

Another researcher that has analysed and described how to best design work stations for both humans and automation is Sheridan professor at Oxford University [36]. In one of his papers he is discussing ten statements that describes what to consider when implementing automation close to humans. These ten statements are:

1. Allocating to the human the tasks best suited to the human, allocating to the automation the tasks best suited to it.
2. Keeping the human operator in the decision and control loop.
3. Maintaining the human operator as the final authority over the automation.
4. Making the human operator's job easier, more enjoyable, or more satisfying through friendly automation.
5. Empowering or enhancing the human operator to the greatest extent possible through automation.
6. Generating trust in the automation by the human operator.

7. Giving the operator computer-based advice about everything he or she might want to know.
8. Engineering the automation to reduce human error and keep response variability to a minimum.
9. Casting the operator in the role of supervisor of subordinate automatic control system.
10. Achieving the best combination of human and automatic control, where best is defined by explicit system objectives.

Sheridan is however arguing for that there are no algorithms or answers that are correct every time when it comes to designing a system with both man and machine and that a decision based on the unique situation needs to be made [36]. For example, it is very hard to know exactly when it is good or bad to let the human have control over the robot. Another example is the concern of doing the job easier or more enjoyable for an operator. Automation often lead to less heavy hands on work for operators and more work of a monitoring type, something that many operators think is very boring.

3.2.2 Level of Automation

The theory of Level of Automation (LoA) is used to understand the function of tools and information used for different tasks on a work station [37]. The LoA can then be used to, in a systematic way, evaluate work tasks and understand if the help to the operator is sufficient or not. The LoA can also be used to evaluate and understand what for example quality issues can be due to as showed by Fasth et al.

The level of cognitive automation is the help the human gets from a machine, PC, instructions or other predetermined system to understand and interpret what to do and how to do different work tasks [37]. Level of cognitive automation can, in the same way as physical automation be increased to help the human understand and perform work tasks better.

Fasth et al. describes a scale on which to categorise what level of automation a task is belonging to [38]. The level of automation has been divided into cognitive and physical automation. Cognitive automation is help from information and tools to understand what and how to do things. Physical automation is what tools are used as help to perform tasks. Furthermore, the same author has analysed how quality issues can be coupled to complex work tasks and low level of automation. In a case study done in the vehicle industry Fast et al shows that there is a connection between high station complexity, low level of cognitive automation and high numbers of quality issues. This result show that it is important to consider what cognitive tools are used as support at stations and try to increase the level of cognitive automation to increase quality of work. Fast et al has divided cognitive automation into seven different levels where 1 is the lowest and means no support at all other than the knowledge from the operator and 7 is the highest and means that no human thoughts at all is needed (this can be considered a non-realistic state today).

Level of cognitive automation 1-7:

1. The task is done based on the operators own experience only.
2. The operator is given information on what to do, like information in what order to do certain tasks.
3. The operator is given information on how to do things, like written instructions or pictures.
4. The system needs verification from the operator before it can move on. example can be a fixture that will not go off until everything is done or a computer system that needs some information or confirmation between continuing.
5. The technology is helping the operator to understand what to do. This can be done by lights that show where to work for example.
6. The technology takes over if the operator is doing things wrong. This can be brake functions that corrects spins.
7. The system does things totally manual. Examples are autonomous work cells or cars that can park for themselves.

As for the cognitive level of automation there are a method developed to categorize physical level of automation [37]. The physical level of automation is describing to what extend the operator gets help by a tool, machine or robot etc. The different levels are explained in the list below:

1. The task is done manual without any tool.
2. The task is done by a static tool, a tool that is designed to be used for one task only. Like a screwdriver in one size.
3. The task done by a tool that is flexible in that way that it can be used for different task, like a screwdriver set where the top can be changed and fit different screws.
4. The tasks are done with help from an electric tool.
5. The tasks are done by a machine or robot and the operators task is to start, stop and monitor the process.
6. The task is like level 5 with the different that the machine or robot is flexible and can be used for different tasks.
7. The system can adjust program and change settings between products for itself without human involving. An example is a totally autonomous work cell.

3.2.3 Standardized work

Standardized work is a way to control how operations are carried out[39]. There are many benefits of standardized work such as making planning easier when a certain work always takes the same amount of time. The planning includes line balancing the production, staffing of the station and planning production volume etc. When planning can be done more accurate the company will perform better economically and be able to have a better accuracy to deliver goods in time to customers. One of the success factors for a company is to be reliable and through standardized work the reliability can be greatly improved.

To have a standardized way of working and applying best practise is required to be able to improve the process. If all employees carried out a work differently then you will have a hard time improving the process. This does not necessarily mean that operators will have no impact on how their work will be done, rather the opposite if there is a well-developed organisation in the company. The operators would then be most active in the development of the standard of the work, after all, it is them who performs the work and probably knows it best.

Standardized work is also a tool that eliminates waste [40]. When you have a standard, you know all of the steps needed in a certain process which makes it easy to identify unwanted wastes such as wait, elimination of non-value adding tasks and reduce transport times etc. One more waste that can be reduced is rework. A standardized way of working will make the quality of the products more equal and in most cases higher. The quality will be improved since everyone does the work in the same way applying best practice.

3.2.4 Human-Robot Collaboration

A Human-robot collaboration operation is when an industrial robot and a human perform tasks together in the same work space, the collaborative work space[41]. The biggest benefits of having a human-robot collaboration is that you can combine the flexibility of the human and her ability to handle diversities with the strength, endurance and precision of a robot[42].

Collaborative operations

There are four major variants of human-robot collaboration[41]. They describe different scenarios of how a robot can be used together with a human. The different variants can be found in ISO 10218-1:5.5 and one thing that is persistent throughout the standard is the concern for the safety of the workers. The robot and the operations it performs should never in any way risk to harm an operator.

- **Safety-rated monitored stop**
  In this mode, the robot stops as soon as a human has entered the collaborative workspace. Thus, the human and the robot does not work at the same time close to each other. This can therefore easily be considered as a safe working environment for the worker. The robot is usually stopped by sensors that activates when a worker goes into the collaboration area. When the sensors register that the worker has left the collaborative workspace, the robot gets activated again.

- **Hand guiding**

Hand guiding is when the robot is controlled by a hand-operated device steering the robot's motions. Before the operator can take control over the robot and enter the collaborative workspace, the robot has to be stopped. When the robot then is controlled by the operator it can only move at a certain speed to assure the safety of the operator. In this variant, the robot can do tasks alone and when needed be guided by an operator.

- **Speed and separation monitoring**
  In this mode, the robot and the human can work and move simultaneously inside the collaborative work space. The robot can only move at a certain safe speed when a human is close and has to keep a protecting separation distance to the worker at all times. If the distance between the worker and the robot gets to short, the robot system stops. The separation distance is corresponding to the speed of the robot motions. If the robot moves slower, the separation distance becomes shorter. Formulas for calculating the protection separation distance can be found in ISO 15066:2016-5.5.3.2.3.

- **Power and force limiting by inherent design or control**
  In the last variant, the robot and the human are also allowed to move and work at the same time in the collaborative workspace. This is the only variant where physical contact between the robot and the human is allowed. When this can occur a lot more requirements are demanded from the robot system regarding the safety of the operator. There are three different types of contacts that can occur between the robot and the human. First of all, it can be an intended contact that is supposed to happen and is needed for the operation. The second contact is an incidental contact that does not harm the operator, the operation or the workpiece. The last contact is then when the contact between the robot and the human endanger either the human, robot, operation or the workpiece.

3.3 Human related aspects

In this section focus is on aspects that are related to humans. The term usability is used to discussed issues concerning factors to make a company sustainable in general and also from an operator point of view. Operator aspects are further discussed in the section ergonomics that is including both cognitice and physical ergonomics.

3.3.1 Usability

The term usability can be used when talking about business and production development and is a so called "umbrella term" meaning it is a term that can be used when describing several factors. According to Mattsson the term usability includes the following words that are all connected to a successful production or business:

Effectiveness is the measure of how accurate and complete the goals are fulfilled. Examples of variables that can affect effectiveness are:

- Quality of the performed task, that leads to the product quality.
- The numbers of problems that occur in the production.

Efficiency is the measure of how the effectiveness is fulfilled in relation to resources used. Examples of variables that can affect efficiency are:

- The task completion time.
- The number of man hours needed to complete a task.
- Time used to study manual or instructions.

Satisfaction is the measure of how satisfied the users are with a product (Could be how satisfied the operators are with a work station). Examples of variable that can affect satisfaction in a negative way are:

- Dissatisfaction in work
- Frustration in work
- Lack of trust in automation

To be a successful company it is given that the strive should always be to increase those three measurements. The following subsections aim to represent different aspects that can all be variables in the usability term when it comes to human-industrial robot collaboration.

3.3.2 Ergonomics

Cognitive ergonomics
What makes the humans superior over robotics in some applications is their abilities to hear, see [24], feel and understand the surrounding. The human brain can respond to and interpret information very quick and is therefore extremely flexible in a production process. Humans however do also have limitations for what the senses can perceive. In a production environment it is important to simplify the interpretation of the environment and the tasks to ensure a good quality of the production and a safe workplace for the operators.

The brain works best when the human is relaxed, rested and when a sound volume of information is being processed [24]. It is therefore important to design work stations for jobs that require a lot of cognitive concentration in a way that is supporting the humans in the interpretation of the tasks[43]. If the tasks are stressful or hard by nature it is even more important to think of the design of the work station.

To interpret the surrounding we humans use the five senses vision, hearing, touch, smell and taste[24]. Vision and hearing is the most important and dominant senses and is also something that is reduced by age. It is therefore important to design workstations with enough lightning and for example signals that is well heard for people of all ages. The hearing is also important to consider since that sense can be damaged with to high sudden noises or constant noise that leads to fatigue.

The brain can process information gathered by the senses in two ways either unconscious and automated or conscious based on previous knowledge, expectations etc [24]. It is important to understand that different operators can respond to information from the senses in different ways depending on background and experience level and therefore information needs to be clear and easy to interpret for all operators.

It is also important that the operator can concentrate on only one thing at a time since humans are easily missing information and taking wrong decisions when concentration is divided [24].

To assist the operators in perceiving and interpreting information mental models can be used [24]. Mental models are based on expectations from humans on what information to find next and where to find it. This is for example the expectation that a green sign means go and a red sign means stop. It can also include where to put information on a screen and when to show each information. If the information given is aligned with what the operator think will happen it is more likely that the operator will be successful in the execution of the tasks.

Physical ergonomics

Ergonomics should be of great interest to the employer since bad ergonomic postures can lead to huge problems for both the company and the employee. In many industries of today humans must handle both heavy and bulky parts, often with some kind of lifting equipment as help but still with a risk of getting injured [32]. Studies has shown that as much as 30% of European manufacturing workers are suffering from lower back pain. This large amount of the workforce being physical affected by their work tasks leads to great costs for both companies and society. For this issue robotics and automation has been the solution in many industries. The robot can help with holding and lifting of the products and moving products and applying forces in a safe and predictable way.

In the future, it will be even more important to consider the ergonomics since rules and regulations are becoming enhanced [24]. One of the reasons for the sharpening of the rules is the demographic change that means an older population. Governments cannot longer afford to let people retire at the same age as before and therefore the jobs need to be adapted to fit older people and also to make people that are young today be able to work until the new age of retirement.

There are several aspects of ergonomics to consider. The first one can be called musculoskeletal fatigue and can come from repetitive work done during many years with relative small loads or injuries through heavy or dangerous work positions. In the last type, the injury can emerge fast and tasks that can lead to those injuries are important to get rid of through design changes already in the planning of a new work station. For the type of issues that will arise first after several years of the same work tasks they can be harder to notice since they may seem harmless at first glance. But for many workers in the industry the same tasks are carried out every day many times a day. To be able to stand the whole work life the tasks therefore needs to be well designed.

In Sweden it is the governmental controlled insurance office "Försäkringskassan" that keeps track of and helps the companies pay for sick leave of employees [44]. When it comes to sick leave in Sweden it is important to differentiate between long term and short term. The reason why it is important to differentiate these two types of sick leave is the Swedish work regulations that regulates the company to pay 80% of the employee's salary the first 14 days of a continuous sick leave period (accept from the first day when no money at all needs to be payed to the employee). After the first 14 days, the Swedish national insurance office steps in and pays for the employee. This means short term sick leave is the sick leave that directly leads to cost for the company while long term sick leave can lead to indirect costs for example need for recruitment or a need for training of stand ins.

A lot of research has been done during the years and it exists several different evaluation methods that can be used to determine what impact certain work tasks have on the operators [24]. It exists many different evaluation methods that are created to evaluate different things. Examples are:

- REBA- Rapid Entire Body Assessment
- RULA- Rapid Upper Limb Assessment
- Niosh lifting equation – used to evaluate lifting

The latest research however is letting the work designer simulate the work tasks and objects being handled. The program then simulates the workloads from the different positions and it is possible to see if there are any tasks that should be designed different. The simulation programs can also often simulate different sizes of humans to see how the tasks are impacting both long and short, men and women.

3.4 Robotic safety aspects

This discuss safety regarding robotics is described, where to find regulations and what they include and what existing technology there is that can be used to make the work safe for the operators.

3.4.1 Safety and regulations of robotics

There are a couple of different rules, regulations and ISO-standards that must be considered when working with industrial robots. There are laws about what is legal to do and there is ISO-standards guiding companies how to follow these laws. In Sweden, it is foremost *Maskindirektivet* a company has to comply to. It is a commission which regulate what is legal regarding machines in general, how the machines must be designed to be legal to sell within EU e.g.

An industrial robot is classified as a partly completed machinery[45][46]. That means that an industrial robot must follow all regulations regarding partly completed machinery. Some of the regulations about how industrial robots has to be designed in Sweden can be found on the Swedish work environment authorities. The main regulations are presented in Swedish Work Environment Authorities provisions about machines, AFS 2008:3.

All of the regulations have a common demand, A total risk analysis has to be performed to ensure the safety of the humans. The risk analysis must look at all possible errors that can occur in all thinkable situations to finally be able to decide if the system can be considered as safe or not.

ABB has developed a mode for their robots to make them more safe to work together with and it is called SafeMove2 (second edition)[47]. SafeMove is installed to the robot controller and connected to sensors that continuously registers the position of the present operators. Depending on the operators position the robot works in different speeds. Slower the closer the human is to the robot. Different zones are usually painted or in some way visualized on the floor. The zones are supervised by the sensors and the sensors controls the speed of the robot.

3.4.2 Sensors and safety systems

Sensor can be used for different applications. They can be used to measure and detect differences in distances, to read bar codes and register products, recognition of geometries and much more. Different types of sensor are used for different applications. One thing that all sensors has in common is that they can be integrated to a larger system. A system that can control a robot depending on the sensor e.g. The sensors most relevant for this study is described below.

Scanners
The most common scanners monitor an area, a 2D field. It can detect if something enters the area and also when the area is empty again. Many scanners can divide the area in different fields that can work individually[48]. 3D scanners also exist but they are usually not used for safety purposes partly because according to SICK the technology is relatively new compared to 2D scanners and not yet tested for safety purposes.

Safety light curtain
A safety light curtain is made up of 2 parts. One is the transponder and one is the receiver of the signals. By this a 2D field is created but it is much more regulated than it is for a scanner, it cannot be wider than the length of the 2 parts. Since the technology is simpler the product is also cheaper.

Vision system (Camera)
For recognition of geometries a special kind o camera can be used. The cameras can also detect the position of a detail and send that information to a larger system so that e.g. an industrial robot can get the information on how it should pick up a product.

3.5 Prerequisites for HIRC found in literature

In this section, the prerequisites for HIRC at GKN that can be found from the theory will be summarized.

Prerequisites used for the checklist:

- The investment of the new HIRC system needs to correspond to a ROI that is acceptable at the company. (From section *Cost of robot implementation.*)

- HIRC will be most useful for stations with medium sized batches and medium number of variations. Very high batch sized is often better to fully automate, low batch sizes can be hard to automate at all. (From section *Collaborative robotics.*)

- To get most out of HIRC, an optimal task division needs to be done to let the operator do the task best for human and the robot the tasks best for automation. (From section *Task division, MABA-MABA.*)

- Efficiency, effectiveness and satisfaction are important for productions and a prerequisite will be to strive against increasing them. (From section *usability.*)

- Physical ergonomics needs to be considered both according to work law regulations and to make sure that the workers can perform their job without being injured. (From the *physical ergonomics.*)

Prerequisites that has to be considered when implementing HIRC:

- The regulations from *Maskindirektivet* needs to be followed to make the station legal. (From section *Safety and regulations of robotics.*)

- The automated system needs to be adapted to the operator in best possible way. (From section *Task division, Sheridan.*)

- The right LoA needs to be used to make sure the operator gets the right amount of help. (From section *Level of Automation.*)

- Cognitive ergonomics needs to be consider to make the operators understand the work task and perform efficient. (From the *Cognitive ergonomics.*)

- A comprehensive safety analyze stating all the technical details that will need to be in place for a safe work place needs to be done. The available technology today consists of scanners, sensors etc that needs to be used. (From section *Sensors and safety systems* and *Safety and regulations of robotics.*)

  Even though the first prerequisites are stated as "prerequisites for the checklist" it needs to be mentioned that those prerequisites are used for the design of the station as well.

4
Results

The first part of this chapter will present the two sub goals of the project, how they were achieved and how the goals were fulfilled. The research question will also be answered, through results showing prerequisites from HIRC and benefits from HIRC.

4.1 Check-list, Sub goal 1

This section will describe how the check-list was developed and the reason for the prerequisites it contains.

In the project 4 stations at GKN were chosen, based on observations, interviews and theory, for deeper investigation. The 4 stations were the following:

Milling machine, a station were the task was to change cutters of the tools of a milling machine. This station was chosen due to identified ergonomic problems that was calculated to arise from an increase in volume of products.

Manual wash, a station were manual washing was performed. It was also chosen due to the ergonomic loads on the operators.

Masking, a station where masking of components were performed to enable thermal coating in the next process. This station was also considered due to the ergonomics but also since there was interests in increasing the efficiency.

Inspection, a station were the operators performs inspection tasks which the measuring machine cannot do. This station was selected because the human abilities were crucial for the tasks at the station.

To evaluate which one of the investigated stations that would be a suitable pilot station a checklist with prerequisites was made. The prerequisites in the check-list were based partly on the study from GKN and partly from the theory chosen as the foundation for this project. The aim was to find a station where HIRC could increase the automation level and take away tasks that was not suitable for humans. However, since GKN operates in a competitive global environment the company also wants to make sure a HIRC will not contribute to a more expensive production.

Prerequisite	Reason	Empirical sources	Literature sources
1. The station is mainly manual in the current state	A prerequisite from the company was that manual stations should be investigated since they wanted to increase the loA in the manual work tasks	The Ergonomics could be improved at the station if a robot would do heavy or monotonous tasks	Theory about demography showing that the number of available workers will decrease and therefor the LoA should not be decreased on already automated stations.
2. A fully automated solution for the station is not possible or very difficult/expensive to achieve	An investment has to be economical defensible and possible to implement. If a fully automated solution is not possible, a HIRC could be.	Interviews with project leaders at GKN	Theory about cost calculation and usability
3. There are tasks that a human must do because of the complexity of the task.	If the characteristics of human is not needed, a fully automated solution is often best	Interviews with robot group that thought a fully automated solution is better when possible.	Theory about MABA-MABA
4. There are tasks that the robot can perform better	If a human can perform <u>all</u> work tasks better, there are no reason to invest in a HIRC		Theory about MABA-MABA
5. There is enough space for the robot and the human(s) to work together at the station.	There must be available space for the human to avoid the robot when necessary, there should be no risk of getting hurt	Some station had limited space available and was evaluated not suitable for HIRC because of safety	Safety and work regulations, ISO standards, national work regulations and work directives.
6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.	When work can be divided in this sense, there is no need for HIRC since collaboration wont be utilized	Observations from the investigated stations, particularly the milling machine which will be described more detailed in the next section.	
7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.	Companies will not make an investment if it will not pay off. Unless, there is a critical issue that has to be resolved instantly	Interviews with managers and project leaders. At GKN some investments had been done mainly to make the work conditions better for the operators than for profits.	Theory about cost and investments

The check-list can be summarized like this:

- ☐ 1. The station is mainly manual in the current state
- ☐ 2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.
- ☐ 3. There are tasks that a human must do because of the complexity of the task.
- ☐ 4. There are tasks that the robot can perform better.
- ☐ 5. There is enough space for the robot and the human(s) to work together at the station.
- ☐ 6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.
- ☐ 7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

4.2 Choice of station

This section describes the 4 stations that were investigated, and how and why they fulfilled the prerequisites from the checklist.

4.2.1 Stations not chosen

Milling machine

This station was part of the pre-study since the manual work at this station led to high musculoskeletal loads on the operators. The operation of milling is done completely automatically by the machine but the cutting tools need to be changed often and this is done manually. The manual work of changing cutting tool is made by opening a small door on the side of the machine, gripping the tool and lifting it out of the machine. The door to the machine is placed on a height that makes the operators lift in a bad position and the small door makes it hard to grip and lift in a natural and non-harmful way. The actual work of changing the tool cutting edge is done by removing built up edges by a knife, loosen small screws by a hand driven screw driver, turning the tool edge, tighten the screws and put back the tool in the machine. Each tool has 5 tool edges that needs to be unscrewed and turned and the whole task take about 3-5 minutes. A new product will start to be produced with a cycle time of over 10 hours and around 100 tool changes. With this new volume, the strain on the operators will be too high if the operation will continue to be all manual as before. Examples from other parts of the company with similar work tasks has shown that the operators doing this job frequently are over strained and due to that injured. Both managers and operators that were interviewed agreed that automation would need to be used for the heavy tool change and were interested in starting an investigation about HIRC. Human-robot collaboration at this station could have taken away the hard job of loading and unloading and to start with an idea of the robot helping with some of the screwing was discussed.

However, since this issue has been addressed before in the factory it does also exist one solution for an automated concept that take away some of the heavy work tasks. The solution is a robot that does the work of loading and unloading the tools in the machine. When unloading, the robot put the tool in a stand for the human to do the last job of turning the cutting edges. This job is fiddly and requires a human “touch” to be able to unscrew and turn the cutting edges that can be hard to get loose. Even though this job as well can cause fatigue on hands and wrists this job is considered very hard to automate. The problem of the cutting edges lay in an initial stage in the design of the tool and should be considered of the suppliers of tools to solve the root cause problem.

Check-list for the milling machine

The check-list fort the Milling machine station is showed below.

- ☒ 1. The station is mainly manual in the current state
- ☒ 2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.
- ☒ 3. There are tasks that a human must do because of the complexity of the task.
- ☒ 4. There are tasks that the robot can perform better.
- ☒ 5. There is enough space for the robot and the human(s) to work together at the station.
- ☐ 6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.
- ☒ 7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

The two major reasons why it was not chosen was the following:

1. The robot would do all the tasks in the beginning of the sequence and the operator would then do the tasks in the end.
2. A possible solution for the station already exists

Manual washing

Most parts of the manual washing are tasks that should not be done by a human due to the physical and ergonomic problems they create. Operators complain about pain in neck, arms, elbows and shoulders due to the physical loads that they are exposed to during the manual washing operations. All managers connected to this station are aware of this problem but there have not been any good solutions to this problem so far.

The reason why the manual wash is needed is because of the smear that is left on the detail after it has been processed in the deburring. Many attempts to change the deburring process to reduce the amount of dust created has been done but with little or non affect.

The dust cannot be washed away only by water pressure and therefore some kind of mechanical cleaning like brushing must be done on the details. It is the brushing and the cleaning with pressure washer that causes the damages to the operators. The pressure washer part of the process could be automated with a robot holding the pressure washer and then follow a program designed according to the detail. The brushing part is perhaps a bit harder to automate but since the sequence of the different brushing movements are the same every time it should also be possible to fully automate.

The sequence of the manual washing process in the current state looks approximately like this:

- Connect the detail to an overhead conveyor, move it into the washing cage and place it in a fixture
- Wash it one time with pressure washer to get rid of most of the dust
- Brush it along with the metals using a brush dipped in water with detergent, this is done on both the outside and inside of the detail
- Use the pressure washer again, brush is against the metals using a similar brush.
- Wash it again with pressure washer

In this project, a human-robot collaboration is the solution and the washing process is not the optimal station to continue with since there are no tasks found where a human would be more suitable than a machine. A solution with a collaboration is hard to find since the robot would do best in handling of both the brush and pressure washer and then no tasks is left for the operator to do.
One more aspect to take into consideration here is that the other part of the operators work tasks at the washing station is to process parts in different sinks. All of these sinks contain unhealthy liquids for the operator. This is one more reason to try to find a fully automated solution for the station.

Check-list for manual washing

The check-list fort the manual wash station is showed below.

- ☒ 1. The station is mainly manual in the current state
- ☐ 2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.
- ☐ 3. There are tasks that a human must do because of the complexity of the task.
- ☒ 4. There are tasks that the robot can perform better.
- ☒ 5. There is enough space for the robot and the human(s) to work together at the station.
- ☒ 6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.
- ☒ 7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

The two major reasons why it was not chosen was the following:

1. The root cause to the problem can be solved in a better way, as an fully automated solution directly after deburring or integrated in the deburring station where the problem is caused.
2. There would still be chemicals from the cleaning products that could harm the operator.

Masking

In this station products are prepared before thermal coating. The preparation is made from masking the product with tape so that only certain surfaces will be covered by the thermal coating. Today this job is made all manual by two operators working in shifts. The operators work consists of reading instructions on where to tape and then apply tape to the given parts of the product. A lot of different products are being prepared at the masking station and they vary in both shape and function. Some products are very big and handled with overhead crane and some are so small so they can be worked with in a sitting position by a desk. The masking operation takes a lot of time and need to be very carefully performed. When masking big products, the work can be heavy for the operators since the tape needs to be pushed in place with a significant force. For the big products, it can be hard to reach for the operators and the task of applying force is therefore carried out in a bad position that leads to high strain on shoulders and back.
To fully automate this station would be very hard due to the high number of different products and tasks at the station. A human-robot collaboration at this station would be a robot holding the product. To gain the most out of automating the masking station a hand guided robot with the function of the robot to push the tape in place would have decreased the danger for fatigue for the human. This sta-

tion is considered complex to automate due to this extra function required from the robot and from the great variation in products. The requirement of the robot being highly utilized cannot either be reached since it is only two people working at this station and it is not always big products being masked that would benefit from a robot.

However, the station Is still considered as interesting and therefore a HIRC but not as a pilot station in this project.

Check-list for masking

The check-list fort the masking station is showed below.

- ☒ 1. The station is mainly manual in the current state
- ☒ 2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.
- ☒ 3. There are tasks that a human must do because of the complexity of the task.
- ☒ 4. There are tasks that the robot can perform better.
- ☒ 5. There is enough space for the robot and the human(s) to work together at the station.
- ☒ 6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.
- ☐ 7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

The three major reasons why it was not chosen was the following:

1. The work is complex and at least two robots or one and one complex fixture would be needed to complete a good solution. This could be done but as a pilot station for an untested station it requires a to complex solution.
2. The variation of the components processed at this station is too high.
3. The utilization of the station is low and only the larger components can benefit from HIRC.

4.2.2 The chosen station, Inspection, Sub Goal 2

In this section, the criteria list from the chosen station inspection is presented, further information about the inspection station is presented in next section.

☒ 1. The station is mainly manual in the current state

☒ 2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.

☒ 3. There are tasks that a human must do because of the complexity of the task.

☒ 4. There are tasks that the robot can perform better.

☒ 5. There is enough space for the robot and the human(s) to work together at the station.

☒ 6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.

☒ 7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

4.3 Pilot station

In this chapter, the Inspection station is described more thoroughly. How it works and what improvement potentials that exists at the station will be summarized. In the second section, desirable functions of the future state is suggested from the improvement potentials and the prerequisites from the theory findings. Also a possible new task division for the future state is developed from empiricism and theory about task division. The later part of this chapter will answer to the second part of the research question, what benefits that can be achieved with HIRC.

4.3.1 Background and description

Products

At the station two different products are being inspected. Both components are rear frames of commercial jet engines, turbine exhaust cases. One of the details will decrease in production rate and the other will increase. The product that will be increased is a component used in different air crafts such as Airbus320neo [49].

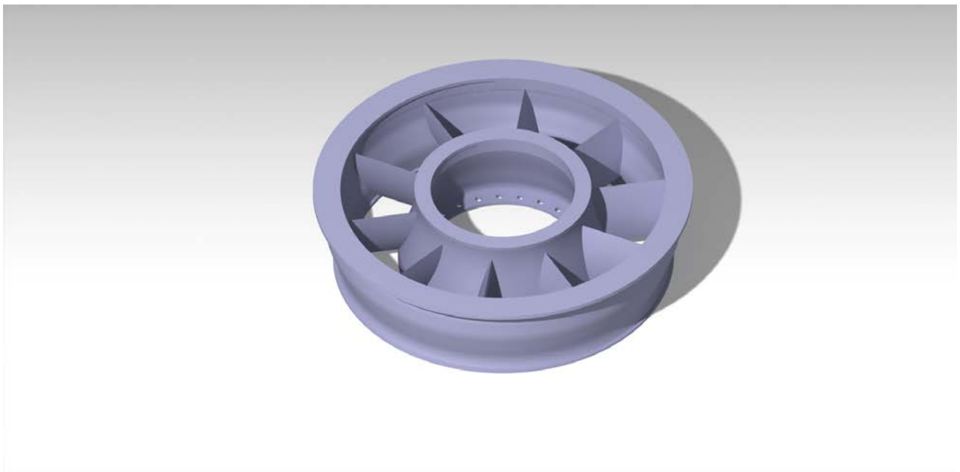

Figure 4.1: Principle model of a rear frame

In this project, the focus will be directed to work connected to one of the components. The detail has a very complex geometry due to the aerodynamics it must consider. It weighs about 100kg, is made of different metals and a principle model of the component is presented in Figure 4.1. The diameter of the detail is about 1200mm. At GKN, the quality is a focus and all handling of the products must be very gentle and operations performed onto them very accurate.

Work tasks and Precedence diagram
At the inspection station two different inspections are done, operation x and y. Both operations involve measurements and inspections (and one marking operation done in x). These measurements and inspections are tasks that for one or another reason cannot be done automatically in the measure machines that are also used at GKN. The operation x is done when the product has gone through all machining needed. In the inspection x angles, heights, radius, Ra, and thicknesses are measured by different handheld analogous tools. The operation y is the final inspection after the final assembly and before shipping to customer. The inspection y does mostly consist of ocular inspection, to make sure no marks or cracks has occurred at the product, but also inspection of edges and burrs is done. In this inspection, all holes and cavities are inspected by fibre optic to make sure no chips are stuck. The operation time for the two inspections are 3-4 hours.

The inspection operations can differ due to different scenarios and therefore the operators cannot be sure that one inspection operation is like the following one etc. To start with the inspection are based on a 100% inspection, an inspection where all the important manual measurements, the so-called requirement numbers, are inspected. However, some requirement numbers do not need to be controlled when they have proven to be stable for a certain number of products in a row. This leads to that only 35-40% of the measurements are measured each time. However, every 10th product will still have the 100% control to make sure no measurements are out of tolerance.

Due to the variation of requirement numbers the operators need a lot of information to be sure the right measurements are done. This list present what information the operator has access to and how it is presented.

- Information that follows each product with the requirement numbers of WHAT to measure. The requirement numbers correspond to different measures and inspection tasks that correspond to the tolerances from the drawing. Sometimes the operators do not know which measurement correspond to which requirement number and therefore the operator needs to consult the physical drawing. The drawing shows different views of the product and the operator needs to understand where on the physical product each view is located. The operator checks the list and the requirement numbers one at a time and checks OK or inserts a measure into the PC-system. This information will lead to a cognitive level of automation of 2.

- For some requirement numbers there are additional information that explains also HOW to do the measurements. This additional information will lead to a cognitive level of automation of 3.

  The same categorization of levels of automation can be made for the Physical tools used.

  The operators use many different tools and some machines to accomplish the inspection. Also there is a need for different kind of tables and fixtures to hold the products in place during the inspection tasks. Different tables are used because the operators need to inspect the product from different angles and thereof the different "fixtures" or work benches. There are 2 electrical cradles and one manual at the station, these are used when the material is "standing up". There is also one spinning round table at the station which is manual, these are used when the products is "laying down". Except these there are 2 more tables better calibrated for certain measuring equipment where the details also can rotate. To move the details between the different cradles and tables cranes are used.

  The inspection operation is carried out with the help of the following tools:

  - Surface roughness stand, LoA 2
  - Digital altimeter, LoA 3
  - Digital Calliper, LoA 3
  - Radius templates, LoA 2
  - Angle templates, LoA 2
  - Thickness gauge, LoA 2
  - Tolerance thread gauge, LoA 2
  - Gage block, LoA 2
  - Borescope, LoA 3
  - Feeler gauge, LoA 2

- Diameter measuring tool, LoA 2
- Diameter measuring tool with gauge, LoA 3

One of each tool are located at the station and shared between the operators. The tools are kept in a drawer on wheels with dedicated places for each tool. The analyse of the production and the work tasks was summarized in a PDM. Since the tasks in the precedence diagram are looped when new inspection tasks are started the LoA can vary and therefore some LoA are stated as intervals.. This symbolizes that sometimes a tool with a LoA of 2 is used and sometimes 3 etc.

The PDM for the operator tasks with their LOA can be found in figure 4.2.

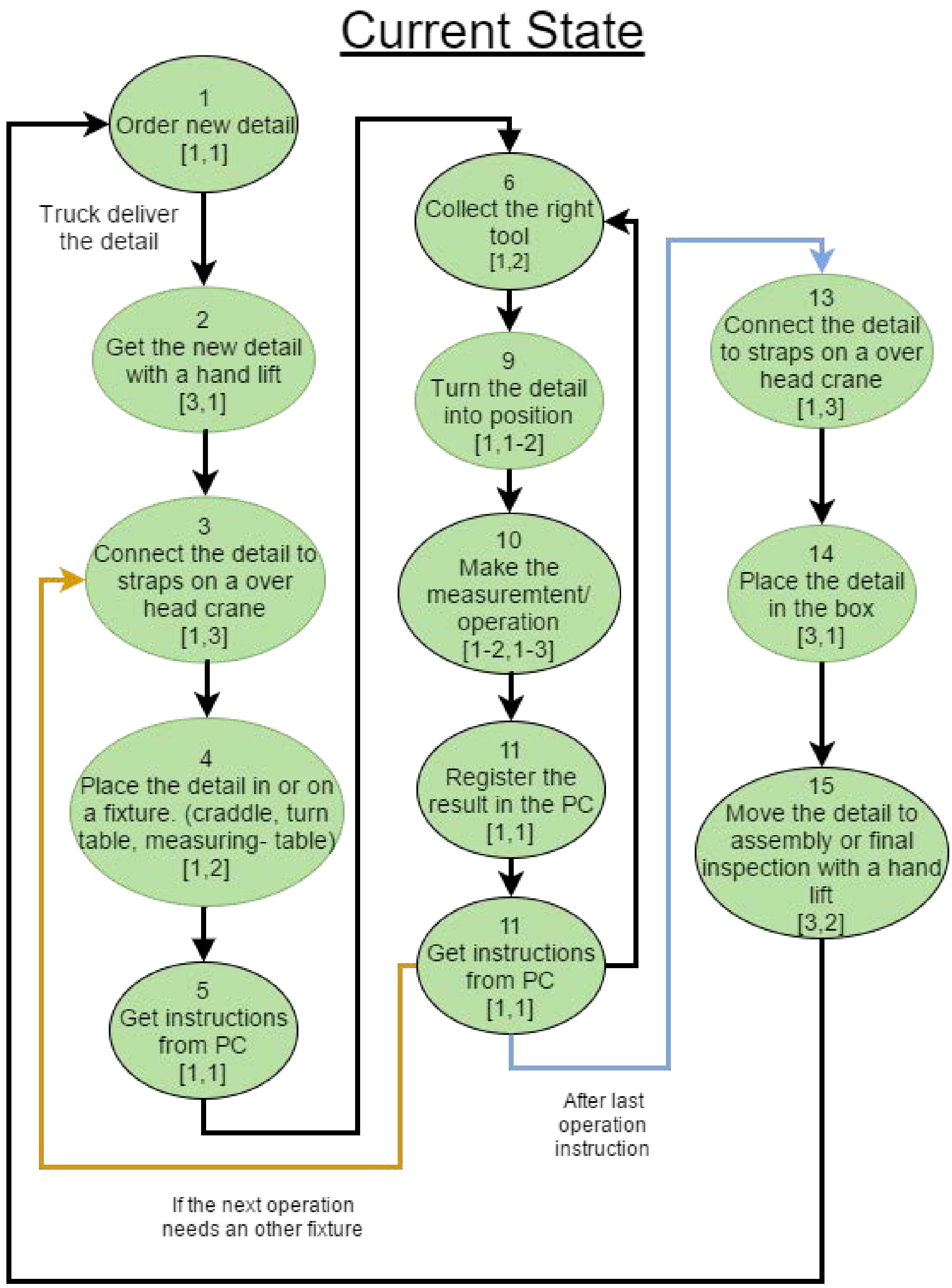

Figure 4.2: PDM in current state. First number is sequential order, last two numbers visualize the LoA [physical automation, Cognetive automation]

Resources and layout

- **Employees**
  There are 8 operators at the station. 6 operators working the GKN-Shift and 2 working daytime hours, 7-15.

Semi-structured interviews were done with 4 out of the 8 operators at the stations and some of the recurrent or most interesting answers is presented here:

Q: What task is hardest to perform?

A: The works task most crucial for the quality but also hardest to perform is the ocular control. Ocular inspection is when operators should decide with their eyes and experience only if something is acceptable or not. Usually there are no instructions on what to look for and what should be considered as a quality deviation. The operators need to decide for themselves if they think everything looks normal. The ocular inspection is very different from inspection tasks where measures are taken since there are no real answers to what is right or wrong. It all comes down to the experience of the operator.

Q: What do you like most and least with your job?

A: The common answer from several operators was that they liked the actual inspection work but did not like all the administrative work. Two of the operators expressed that they thought working with the computers and the IT-systems was complicated and hard to learn. Also, most of the operators complained on the physical protocols that follows the products and said that it can be hard to remember to fill them in. That can also make it hard to know if someone else forgot to fill them in or if inspections was not done.

Q: Do you get stressed sometimes?

A: At the day shift when four operators are working at the same time it can feel crowded at the station. According to the interviews this can lead to stress and unnecessary movements to get out of the way for a colleague that needs to have a special work place for a short time, as an example.

Q: Are there any tasks that are dangerous?

A: The material handling is a problem at the station. The handling is done with overhead cranes and slings, it takes time and can hurt both operators and the material. One of the operators is mentioning that the material handling is one of the things that can lead to getting pinched and injured and there have been injuries before on operators from turning the material when non-electrical turning tables was used. The material is very heavy and if the handling is not done carefully and in a correct way there are risks of scratching and making marks on the material. In the inspection station a scratch or mark would be very unfortunately since this is the last station before shipping and there is thus no other station left in the process that could fix the mark.

- **Layout and logistics**
  When products are ordered they are supplied by forklift and put on a space

outside the inspection station. The products are supplied in big wooden boxes that are also used for transportation to customer. The operators collect the boxes by a manual pallet lifter and transport them to their workstation. An overhead crane is then used to pick up the product and put it in either a turning cradle or on a table. The layout in the current state can be seen in Figure 4.3.

After operation x the product is once again packed into the wooden box and driven by a manual pallet lifter to the room next to the inspection where the final assembly takes place. After the final assembly, again the manual pallet lifter is used to transport the wooden box back to the inspection station for operation y.

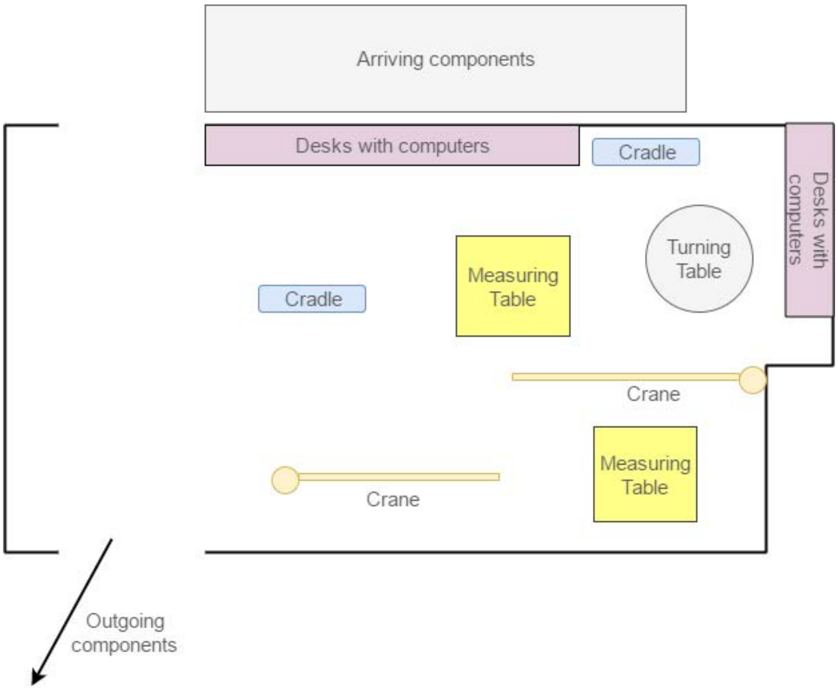

Figure 4.3: Layout of current state of Inspection

4.3.2 Data gathering and analysis

In this section results from analyses of the production are presented. The analyses in this section is of a quantitative character and the aim is to give objective results.

Ergonomic evaluation

When doing the ergonomic evaluation the GKN standard for ergonomics was used (see appendix B for examples from the standard). The tasks at the station are shifted often since a lot of different measurements are done over a long period of time. Most of the time inspecting the products the operators are standing upright in a straight position without raising the upper arms and with the lower part of the arms only slightly bent. The head is sometimes bent but not for a time that is longer then the recommendations from the standards. Most of the work characterized as “administration/PC” is done sitting on a chair by a desk. Sometimes inspection tasks are also done sitting on a movable chair in front of the product. There are neither heavy lifts at the station but sometimes the operators need to apply significantly large forces to control and handle the material. The task of turning the product manual in a fixture is sometimes done since there are not enough electrical turning fixtures for all operators and therefore the non-electrical turning fixtures are used.

The frequency study has shown that around 6% of the operator’s time is spent working in postures that are considered as bad (orange or red) according to the GKN ergonomic standards (See appendix B). However, these 6% consists of different tasks and positions that are bad for different limbs. Combined, these tasks does not qualify to be dangerous to humans since they are not repeated or static. Some of these tasks could yet be bad for the quality of the products since they are not normal positions to the human body and therefore inspections that requires these “bad postures” could lead to less time than needed spent on the task, it is indicated from the managers that this could be the case. Also for those postures where the operator for example needs to bend his head to see behind an edge or similar this can lead to the operator not being able to see good enough.

Sick leave is something that can be considered connected to ergonomics. Sick leave can occur either due to heave physical work or high psychological pressure. The direct cost for sick leave at the station cannot be calculated due that individual numbers of sick leave are confidential handled by each manager and HR department. Numbers that are public can however be found from each production department including 10-50 operators. These numbers can then be compared to the company.

At the inspection station the units of sick leave are:

- 3 units the last 12 months
- 4 units the last 4 months
- 2 units the last month (march)

For the company in whole the units of sick leave are:

- 5 units the last 12 months
- 5 units the last 4 months
- 5 units the last month (march)

In this statistic both short term sick leave (up to 14 days) and long term sick leave (over 14 days) are included. The company do not keep any statistics on the two types of sick leave separate. But there are neither higher or lower numbers on sick leave on this station than the rest of the stations at GKN and the number of sick leave at GKN are good compared to other companies.

Even though there is no statistics on these two types of sick leave it is possible to see if there is or have been any long term sick leaves during the most recent months. In the inspection station, there are only one employee that are home due to long term sick leave and this is only for 25%. The HR department interviewed is therefore commenting that the sick leave numbers at the inspection station, are following the numbers of sick leave in general for the company.

Cost analysis

The cost analysis was done to gather data on what costs could be found at the pilot station in the current state and how these costs would increase or decrease with a HIRC. Costs was gathered from documents from the financial department and for variables that was not measured frequently, costs was estimated from experience from project leaders and managers at GKN.

Cost for implementation of a HIRC was asked for from the supplier of automation solutions. However, the supplier did not have resources enough to calculate a price for a solution that was not sure to be installed. Then cost for installation, operation and maintenance was estimated from the GKN department of automation.

The final cost calculation will not be presented in this report but to answer the part of the research question "..what benefits could be seen..": one benefit could be economical after the first years of payback time.

Frequency study

To collect data and information about the station a frequency study was done. The frequency study was used to understand what tasks was carried out and how much of an operator's time was spent on each activity.

The study was done by observations and in total a number of 324 observations was done from 6 different days at the inspection. On the manual inspection station, all four operators was measured at each interval. The measurements from the frequency study was done every 10th or 15th minute and was noted on a sheet with predetermined work task categories.

The frequency study gave useful statistics to analyse when finding improvement potential in the station and can be summarized as below:

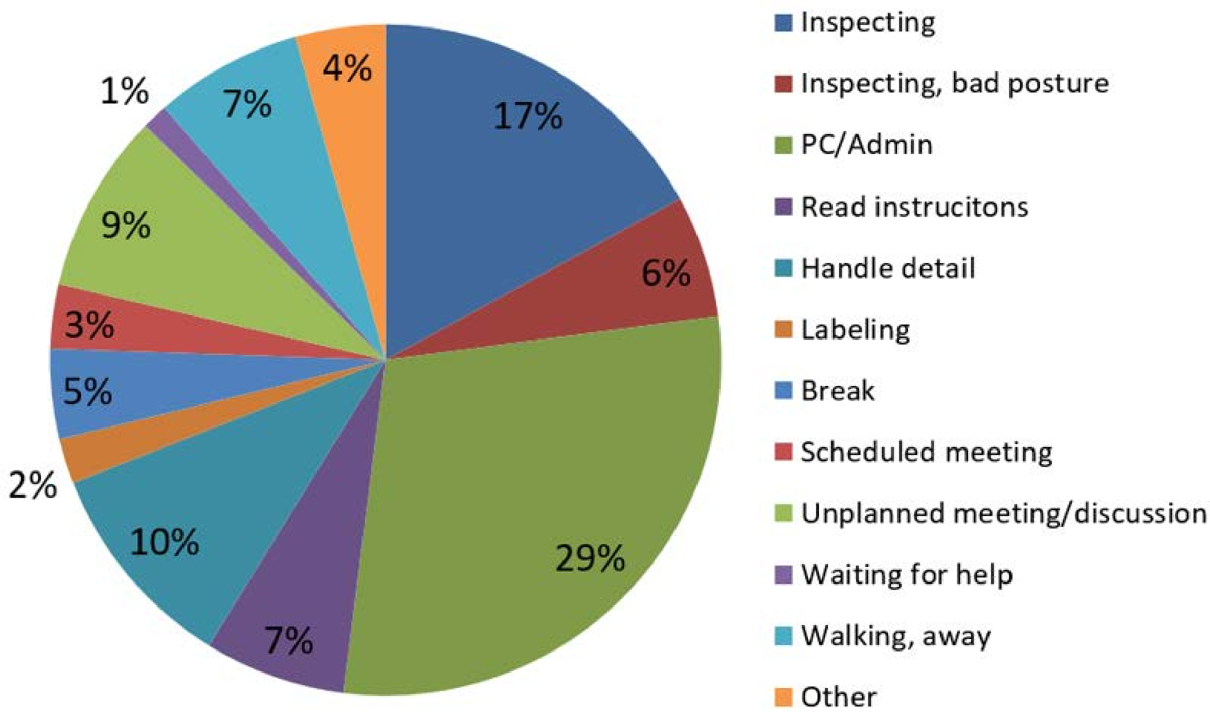

Figure 4.4: Frequency study

The frequency study in the inspection was divided in 11 different categories for tasks that frequently occurred. According to the study the time spent on the actual work task inspection was only 23 percent of the time while the biggest individual tasks category was PC/admin. The category inspection was divided into two different categories, one was called "inspection" and the other one was called "inspection in a bad position". Other significantly big categories were material handling, reading of instructions and unplanned meeting/discussion. The frequency study shows that there are great potentials to increase the overall efficiency if those categories, that can be seen as waste, are decreased. The category "inspection in a bad position" was relatively low but however every aggravating of the task inspection can lead to quality issues that can be tremendously dangerous for an airplane engine. Therefore, the result of the frequency study could also show that there are room for improvements of the ergonomic situation of the operators.

Conclusion of issues at the Inspection

After the two first steps of investigation of the station conclusions of the main improvement potentials was found.

- Only 25% of the operators' time is being occupied by inspection tasks. Pc/admin is the task requiring most time but also material handling takes a noticeable amount of time.

- The material handling can lead to quality issues and can hurt the operators.

- It gets crowded at the station during day time and waiting time and additional material handling can occur.
- The computer systems are not very liked by the operators. A lot of time is spent in front of the PC instead of doing actual inspection tasks.
- The ocular inspection is very demanding since it is hard to know what is right or wrong. The ocular inspection can only be learned through experience.
- The inspection task can differ from product to product and therefore the operators do always need to check the list of requirements numbers to make sure the right measurements are done. This is also affecting the cycle times that can differ and it is hard to keep track on exact operation times and therefore hard to plan.
- A lot of different requirement numbers makes it hard to remember them all and the newer operators needs to consult drawings. The drawings consist of many pages and sometimes it is hard to understand all the different views.
- The ergonomics are not significantly bad. However since the inspection is an essential operation to ensure the product quality it is important to give the operators the best prerequisites to do a good job.

4.3.3 Development of a future state

To answer the second part of the research question -*what benefits will the technology lead to?*, a future PDM is developed, the desirable main functions of the pilot station is listed based on prerequisits found in literature and empirical studies and in the end, the benefits of the pilot station are stated.

Work tasks and PDM

Based on the PDM-LoA-MABA-MABA from the current state, the tasks were analysed and a future state consisting of HIRC was formed to solve current issues of the pilot station. Figure 4.5 shows how the tasks from the current state are divided between human-machine and how the new work tasks for the operator will be in the future state.

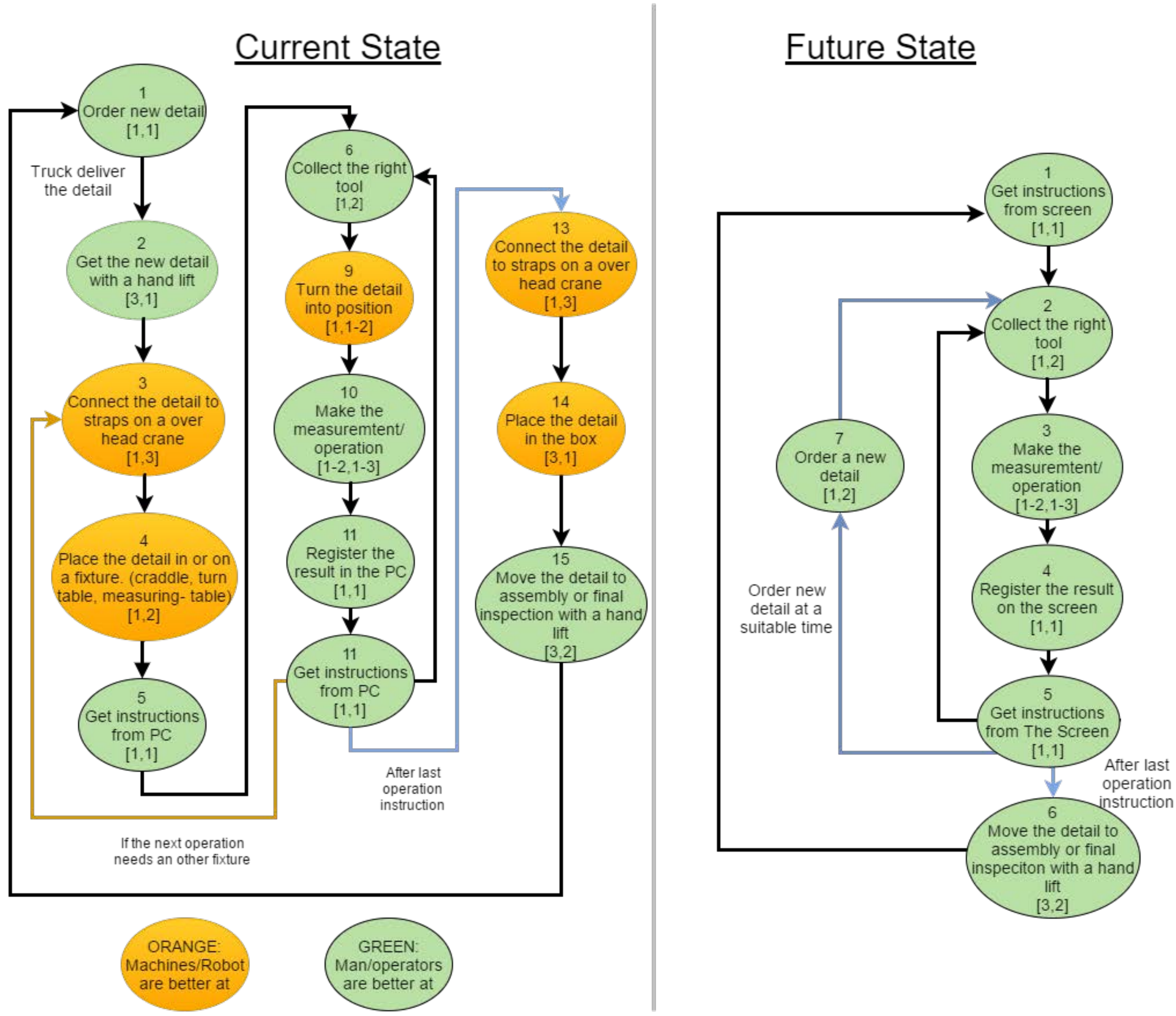

Figure 4.5: Operator PDM

The task division was based upon observations and interviews, but mostly upon the theory about human abilities vs machine abilities. The final suggestion for task division can be seen in figure 4.5 and the main functions of the station is stated in the list below. The first part of the list defines how the tasks at the station is divided and how the robot vs human will do the task in a collaboration while the other part of the list is general requirements of the system. System in this case, is meant an overall system which all parts are connected to. The robot, the source of information to the operator, the computer, sensors and other safety components etc.

Functions of the station

- The operator should order the product since the planning of today is not stable enough to automate.

- The robot will do all the lifting and arranging of the material, this means present the material for the operator in the most optimal way.

- The robot should have different positions steered by the list of requirement numbers that already exists today, where every requirement number should correspond to a robot movement.

- The operator should be able to steer the robot to next sequence in the robot program when he/she is done with inspecting one requirement number.

- The operator will do all the manual control tasks.

- The robot should put back the product in the wooden box when all inspection tasks are done.

The following tasks are considered as functions that needs to be provided by the system in general and not only for certain tasks:

- The requirement and information of HOW to do tasks should be showed to the operator by a computer located in the station. - theory about cognitive ergonomics, Sheridan and indications from frequency study that too much time is spent reading instructions.

- The operator should be able to insert the right numbers or "ok´s" in to the same computer and that will be required before next robot movement. - theory about cognitive ergonomics, Sheridan and indications from frequency study that too much time is spent reading instructions.

- The station should prevent any danger for the operator of getting injured through an accident or through fatigue from monotonous and bad working positions. - ISO Swedish work regulation law.

- The system should prevent any danger for the material of getting damaged through material handling. - Interviews with operators and quality manager.

- The robot used in the system should be programmed so that the material is always presented for the operator in a way to reach the best ergonomics, efficiency and quality of the work. - theory about how to divide task (robot will do the hard job of handling the material. Theory about usability.

- The system should be flexible to correspond to different heights of the operators and requirements of working standing or sitting (when possible). - theory about usability.

4.3.4 Benefits of HIRC

Potential benefits from the task division are stated in the following list:

- Less risk of the product being damaged when lifted and put back in box when done in a standardized way by a control robot motion.
- The most dangerous tasks for the operators, material handling is removed.
- A lot of time can be saved when walking, and searching for right information are reduced. With a system that instead of taking time from the inspection tasks is helping the operator the work is thought to be more efficient.
- Possibility to get standardized work through letting the robot guide the work tasks.
- The system can be used to collect data to base continuous improvements on.
- Division of tasks that are best suited for Man vs Machine. The 10 statements of Sheridan are used to make sure the final design is a good solution for the operator.
- Enhancement of the operator through letting him/her focus on the actual work of inspection and deciding what is a quality issue or not.
- The new system that is connected to the robot program opens up possibilities to share information and get additional information about every task.
- HIRC is in line with industry 4.0 and the initiatives and research going on both in Sweden and abroad. This can be seen as technology is being presented with functions supporting automation.
- When the system is simplified and the robot is helping with work task order and sorting information from the operator there will be less tasks to learn. One positive effect of that could be that the learning time for new operators is decreased.

In Appendix C, there are a suggestions about more areas and details of how the Inspection could look like in future state. There is also an evaluation on the conceptual model of the future state.

5

Discussion

The discussion is written to further highlight and give space to some of the findings that has helped to answer the research question. The discussion is also written as a help to interpret the results and understand how and why the results was found.

5.1 Prerequisites for HIRC

The research question for this report was: *What would be the prerequisites to consider when implementing HIRC and what benefits will the technology lead to?*. The answer to what prerequisites to consider was a check-list with prerequisites to use when deciding if a station is suitable or not for HIRC, and also prerequisites to consider when designing a HIRC.

In the beginning of this project, one of the most important questions was if a HIRC could be possible at all today. The main concern was if safety regulations would accept a human working close to an industrial robot and if there was technology advanced enough on the market to make a HIRC safe. The findings from the Swedish work regulations showed that there were no rules against using HIRC if a comprehensive safety investigation was performed, and systems were installed to protect the human [42]. When investigating if technology advanced enough already exist on the market, it was easy to find solutions describing advanced sensors and light curtains that could be connected to the robot and make the work environment safe for humans [48]. An interview with a supplier(LKN Industriautomation) working with installations of automation solutions did not see any problems with making the concept of HIRC safe enough either. This resulted in the answer that the prerequisites in form of technology and work laws was in place for consideration of HIRC.

5.1.1 Check-list

To create the check-list, the first part of the research question was used to investigate the prerequisites that needed to be concerned when implementing HIRC. When the check-list was developed it was in a high degree influenced, not only by theory but also from the empirical study performed at GKN. This means that the check-list probably would work best at companies similar to GKN. Also some of the prerequisites on the list was added from direct findings at the studied stations and since only four stations was studied, some more prerequisites could possibly exist for using HIRC. The following discussion about the check-list aims to explain how general each prerequisite can be interpreted.

The first prerequisite, "The station is mainly manual in the current state", was given from GKN where the management wanted to investigate HIRC only at stations and/or tasks that was manual in the current state. This was considered a good approach since the finding from theory studies showed that both technology development and the demographic development of the society is leading to more automated industries [1][2][50]. However, from an efficiency point of view this prerequisite could be discussed. There could exist situations when an automated station could be enhanced by a lowering of the LoA to a collaboration. This can for example be in situations where a company will increase the number of product variants in the production. In that kind of situation some task could be more suitable for a human since the variation of the tasks could lead to a complexity that would be hard to handle by automation. This first prerequisite can therefore be considered as specific for the analyse of GKN in this project. An investigation about HIRC at a fully automated station where problems occur due to complexity of tasks could with advantage be done at other companies and other projects at GKN.

The second prerequisite on the check-list is "There is enough space for the robot and the human(s) to work together at the station." This prerequisite is considered very general since it is based on Swedish work law regulation that all Swedish companies needs to follow [45][46]. It is based on the specific regulation that a total risk analysis needs to be performed to ascertain the safety of the work place. The safety can in many ways be ascertained by technology but enough available space is a prerequisite to get an approved work station when a robot is used.

The two Prerequisites ,"There are tasks that a human has to do because of the complexity of the task" and "There are tasks that the robot can perform better", did both come from the theory chapter about work task division and, as stated in the prerequisite 4, also from MABA-MABA [35]. However, this was also found in the empiric analyse of the production. A good example was the milling machine station where the final tool change was a task that the management had tried to automate but previous analyses had showed that some tasks was to complex and "fiddly" for this. To gain most out of a HIRC these prerequisite should be considered as general, since another production solution would probably be best otherwise.

Prerequisite five was "A fully automated solution for the station is not possible or very difficult/expensive to achieve." This prerequisite can be said to be general since cost is of essence to all companies [51],[27]. If a HIRC would be less costly than an automated solution it is a solution to consider. However, the previous prerequisites need to be fulfilled to make sure that the work conditions for the operators are ok.

The prerequisite, "The work cycle cannot be easily divided into two parts where the human does the first tasks and the robot do the last parts or vice versa.", was found mainly from investigations from the milling machine. The investigation concluded a solution where a division of work space could be possible. Since the work law regulations require comprehensive safety systems for a HIRC, the cost with additional sensors and safety systems do not defend a collaboration in a common work space if it is not necessary. This prerequisite can also be considered general since working close to a robot can lead to extra risk for the operator and work division should be done when possible [45][27]. One of the delimitation of the thesis was to only consider collaborations where the human and the robot would share the same work space and work simultaneously. If this delimitation was not stated, this prerequisite could probably look different due to the different collaboration modes according to the ISO. could also be when the robot stops as soon as a human enters the robots work space [42].

Finally, the prerequisite "The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues." This is also a general question about cost [51],[27], it has to be economical defensible. But work law regulation can force a company to invest in a new design and if that is the case and all other prerequisites, not considering cost, are fulfilled then HIRC could be applied.

The check-list developed in the thesis can be used as one out of more foundations for companies to investigate if HIRC could be a possible solution. Since it is based partly on a case study at GKN, it is also affected by the characteristics of production in Trollhättan. This check-list does not necessary includes all the possible needed prerequisites but only the ones the authors found, in literature and through empiricism, during the thesis work.

5.2 Choice of station

From the pre-study performed in the production at GKN, it could be seen that the inspection was the most suitable stations for HIRC since it matched all prerequisites on the check-list. However, also the simplicity and the ease to copy the solution to another station was interesting factors when choosing the inspection station. This was since manual inspection tasks are performed in many processes at GKN and the solution could easily be copied to other stations at the company.

Another aspect that was considered during the project was that the authors needed to rely on help from employees at GKN to find answers and do analyses. Due to this, the authors also wanted to make sure that all four of the investigated stations had cooperating personnel to ease the work of the project.

5.3 Task division and functions of the pilot station

To investigate how the task division should look like, theory about ergonomics and MABA-MABA was used. Prerequisites that the right LoA and cognitive automation needed to be considered for the human tasks was found [24], [37]. This theory pointed out the same as the interviews did, the operators thought that handling the component was the biggest health and safety risk and material handling is according to the literature something that a machine/robot is better at.

Interviews with operators working at the pilot station showed that some of the tasks was very complex, especially from a cognitive point of view. One example was the ocular inspection. It was a task where the LoA was very low but the task required a lot of experience. Another example was the drawings that were written in small text and with views that could be hard to understand, at least for people not used to read drawings. It could also be seen from the frequency study that a lot of time was spent on administration and reading drawings. This shows that the information is not presented in the most optimal way for the complex tasks that can be found at the inspection station [24], [37]. Therefore the function "*The system should be able to guide the operator through the right sequence of the work and reporting of measurements etc. should be able to be done immediately in the same system located at the workstation. The system should also provide the operator with all information needed to understand what to inspection and how*". was stated.

The physical aspect of ergonomics is very important to GKN since safety and satisfaction of the workers is highly valued. From the theory the prerequisite about LoA is also concerning this issue [37]. One very interesting aspect of HIRC is the musculoskeletal loads that can be avoided by the operators through right task division. This can be seen in the function description of the future state stating that the robot should present the work piece in the best ergonomic way. However, from an investment point of view it is very hard to calculate benefits from better ergonomics in real money. After investigating this, it has been found that it is hard to align a cost of for example sick leave to a certain work station with bad ergonomics. Sick leave can come from many factors and most often it takes years to be injured from work related fatigue [44]. At GKN there are though experience of sick leave that has very likely been due to fatigue from the work place. Therefore, GKN knows more or less how to design a workplace and when technical aid is needed to help the operator. Due to this, the ergonomic point of view is usually considered when performing an investment calculation and can be a reason to invest. It is thereby not said that all other companies has this decent attitude against ergonomics and their operators health.

The suggestion that the operator can get the needed information about what and how to inspect is based upon the theory from Sheridan [36]. Sheridan is arguing that the computer system should give the operators all information needed and the theory about cognitive ergonomics argues that information should be given in a logic way [37]. This gives the solution that the right information should be presented for each task. This should follow the sequence of the robot program that presents the right part of the product to the operator.

5.4 Benefits of HIRC

The benefits from HIRC that are described in this report are results of potential improvements at the investigated pilot station. However, some of the benefits can be considered more general and other benefits can work as more specified examples of benefits that could be expected.

In the theory, standardized work is said to give the opportunity to get more even quality of products, more even lead times and the possibility to work with continuous improvements [39]. From the empiric evaluation of the pilot station, it was seen that it is a high degree of freedom for the operators. A low level of both cognitive and physical automation gave room for own interpretations of instructions and tasks for the operators which led to different cycle times and different opinions on what was a quality issue. A robot program would not necessary lead to that all operators should work in the exact same way all the time, some flexibility could with advantage be given, but it would at least give the management a tool to make sure that the work is carried out at a certain standard.

The theory about usability shows that one variable to concern for in satisfaction from the operator, is trust in the automated system [51]. The ten statements from Sheridan gives similar input when it comes to how a system should be designed to make a station sustainable for the workers [36]. Examples of these statements are "Keeping the operator in decision and control loop" and "generating trust in the system by operators". To fulfill these statements the design of the system needs to be well-reasoned and deeply investigated.

Another potential benefit from a collaboration will be an enhancement of the human when giving the operator the best possibility to concentrate on the actual inspection tasks. Sheridan is arguing that it is important to allocating only the tasks best suited for humans to humans and vice versa for the machines [36].

5.5 Sustainability aspects of HIRC

When conducting research, one important aspect is to evaluate the consequences of the research. Since this report has suggested an introduction of a new production method to a company, and as an example for other companies as well, aspects of sustainability will be discussed.

Company aspect
Sustainability aspects from a company perspective that have been issued in this report is foremost the aspects of cost and efficiency. However, another aspect is the work law regulations concerned in the report since a company that in a systematic way is breaking the law will probably be shut down by authorities. furthermore, the well being of the operators have been of great concern in this report. To be a successful company there will always be a need to recruit and keep the right people and therefore this aspect will also lead to a sustainable company in the long run.

Operator aspect
Every company rely on the performance of their employees and at the same time all humans have the right to feel good about their life and their work. It is therefore important to adapt systems to human feelings and experiences and to have a human centered approach when designing and implementing HIRC. In this report the human aspects have been considered from several different perspectives such as ergonomics, trust in automation, safety, etc, but it will always be important for companies to do their own analyzes of how technology will affect their employees. One aim of this report was to show what benefits can be found from HIRC and therefore possible disadvantages have not been part of the result. However, through reading the theory chapter and previous discussion it is obvious that HIRC could lead to an decrease in operator satisfaction if designed in the wrong way. Less satisfaction in form of less free will and distrust in the system etc.

Society aspect
In the background of this report the industry is discussed as an important factor for the society, especially in Sweden [1]. Demographic challenges is together with an increased competitiveness on the global market said to be the challenges for the Swedish manufacturing industry [3]. HIRC could be one suggestion to resolve these issues and contribute to a sustainable society. For the issue of not having enough experienced workers HIRC could be a solution in two ways. First, the technology could lead to a more efficient workplace with an decreased number of workers needed. However, the manufacturing industry is one of the most important employers in Sweden and a more sustainable way of solving the demographic challenge would be to design work places that could be adapted to fit all people. For this issue HIRC have great potential. Since the cost for manual labour increases while the cost of robotics decreases it is thus important for companies to learn new ways of using automation [27]. This is due to increased competitiveness and the importance to continue stay strong and contribute to the society.

5.6 Validity and reliability

Validity and reliability are two important topics to discuss in a scientific report to give perspective and thoughts about how and why the result and conclusions turned out as they did [15]. The validity of this report needs to be discussed to understand if the right conclusions was made from the causal relationships found and to what extend the results can be generalized and used by others. In the first four sections of this discussion, 5.1, 5.2, 5.3 and 5.4, the results are discussed to give the reader an understanding of to what extend each result can be interpreted as specialized for the pilot station, specialized for GKN or considered as general. The results that are discussed as general are results where an triangulation from the theory can be done. To validate the internal validity multiple sources of information was used such as interviews, frequency study, own observations etc.

Reliability is also interesting to discuss since the quality of the report can be proved through being reliable. Doing a case study in a running production will lead to a continuously changing surrounding and many factors affecting the context. The results found in this case study was valuable since they gave a clear picture on what issues could be found at a station with many manual work tasks and the theory gave an understanding for what HIRC could be used for. However the reliability is what can be questioned in this single source case study since the results came from a narrow setting that was impacted by many factors, both known and unknown. One of the reasons to why GKN initiated this project was to get an example of how HIRC can be used and what benefits can be seen. This was to raise interest and see where further research should be concentrated. For that occasion the case study fulfilled its´ purpose even though the reliability, in a scientific context, is questionable in a single source case study.

To give the reader an understanding for how valid and reliable each method used in the research approach can be seen a further discussion is concluded in next section.

5.6.1 Research approach

The choice of methods in this thesis was done in an early stage. At that time it was not known where to find all the answers and the only thing the authors knew was that HIRC as they thought about it was not a well-used technology in the industry.

Literature study
One of the factors that could have affected the results from the literature study was the fact that several articles and books used was in some way connected to Chalmers. This is not in a way startling since the report is written at one of the institutions of Chalmers. However, it can be worth discussing if a similar report done at another institution would have consisted of the same theory. The answer is probably not exactly, and the follow up question would then be how that could have affected the result. This is very hard to answer but was considered and therefor other theory was chosen as well. Some of the theory was chosen since it is frequently cited from articles all over the world and also theory from companies and international web pages can be considered to give other perspectives to the report as well.

Most literature that was used was according to the authors still up to date and relevant. Even if e.g. the MABA-MABA theories are very old, they are still relevant since the benefits and characteristic of the human has not changed over the years.

Interviews

To get as much information as possible from GKN, the snowball interview technique was used. This lead to that a lot of time had to be spent talking to persons who did not have an answer to the desired questions, instead, new point of views was always found and discussed. It was hard to narrow down the scope of the thesis since all the people that got interviewed had their own point of view of HIRC. However, it was interesting to not limit the discussions since the free discussions gave the opportunity to understand what topics was actually important for the different stakeholders.

The approach when conducting the interviews was always to ask open questions to make sure to get an honest and not fabricated opinion. When observing and interviewing the operators it was hard not to ask leading questions to make them more interested and positive to the technology of HIRC. In some cases could less open questions probably have led to more accurate but less reliable results. In one of interviews with the operators, two operator were interviewed at the same time. In this case, it was beneficial when the two operators got to discuss their work with each other. More information could then be gathered and it became more qualitative since both of the operators agreed about the discussed topics. The information that emerged during the interview with the two operators was also regarded truthful since both operators were experienced. If one had been experienced and not the other, it is likely that the less experience would agree with the experienced in order not to seem ignorant. This is also of course a personal matter, if one operator had been shy, this type of duo-interview would not have been a good method.

To make more general prerequisites, interviews and observations could have been performed in other industries. This would have broaden the perspective and revealed more prerequisites and benefits of HIRC.

Frequency study

A frequency study will always be better with more data points to make it more accurate according to the formula described in the theory[23]. The reason to the chosen number of points taken was mainly because of time limit and that the observations made at the station pointed to the same result as the frequency study. In the study most points were taken on the day shifts. If more points would have been taken they should have been more spread out on the other shifts and the weekends to make an even better picture of the station as well. Especially since the station was more crowded during the day shift and the work looked a bit different at the other shifts. When the frequency study was performed the operators were aware of it and that could also lead to the results showing other task distribution then if the operators were not observed. This problem is something that is very hard to avoid and has to be taken into consideration when evaluating the result.

5.7 Research project VVHIRC

As stated in the beginning of this report the context of this master thesis was as part of a national research project, VVHIRC. The project aims to develop a software that could be used for simulations of HIRC. The software was tested, not as a way to reach the purpose of this report but to give suggestions on how the software could be developed to fit for the production of GKN with the new knowledge that was gained about HIRC in this project. A test version of the simulation program was used by the authors but since the functions of ergonmic evauations was not yet ready no real results could be gained from the simulations other than pictures that are used as examples and can be found in appendix C. However the simulations program will be further worked on and could in the future be used as tool to investigate efficiency and ergonomic in HIRC.

6
Conclusion

This section will give conclusions about the thesis works result, foremost by answering research question stated in the introduction.

Human-industrial robot collaboration is a technology in its early stage. There are many potential application areas for the technology but it is yet not tested in any significant extent. This thesis was initiated to get a greater understanding for the prerequisites and benefits of HIRC. Below follows the answer to the research question and how the 2 goals of the thesis were fulfilled.

RQ: What would be the prerequisites to consider when implementing Human-Industrial Robot Collaboration and what benefits will the technology lead to?

In this thesis, prerequisites to HIRC were found through a case study and by relevant theory. A check-list for evaluating if HIRC is suitable for a certain station was developed from the prerequisites. The prerequisites covers areas such as cost, efficiency and safety. Benefits of HIRC is stated last in the conclusion.

Sub-Goal 1: Create a check-list for how to evaluate if HIRC can be applied to a station.

The check-list includes 7 different criteria. The criteria are based on literature studies, interviews and observations performed at GKN and the list is presented below:

1. The station is mainly manual in the current state
2. A fully automated solution for the station is not possible or very difficult/-expensive to achieve.
3. There are tasks that a human must do because of the complexity of the task.
4. There are tasks that the robot can perform better
5. There is enough space for the robot and the human(s) to work together at the station.
6. The work cycle cannot be easily divided into two parts where the human do the first tasks and the robot do the last parts or vice versa.
7. The utilization of the station needs to be high enough to make investment in a robot economical defensible or that the current state of the station needs to be changed immediately due to safety or health issues.

Sub-Goal 2: Investigate what kind of station would be a possible pilot station for HIRC at GKN.

When the check-list was completed it was compared to different stations at GKN. The Inspection station was selected to be a pilot station for further research since it best matched the check-list out of the different stations. From a current state analysis, different problems at the station were listed. In the beginning of the project the stakeholders in this project thought that the technology would solve problems related to ergonomics. In the end, it was efficiency and quality that was the clearest possible benefits at the pilot station. A conceptual model of a future state of the selected station is described in the appendix.

There are many possible benefits of HIRC. A list is presented below showing some of the major general benefits this technology could result in:

- Less risk of the products being damaged when a robot can perform material handling.
- Dangerous tasks for the operators can be avoided if the robot can perform the heavy or monotonous tasks.
- Possibility to get standardized work through letting the robot guide thework tasks.
- The system can be used to collect data, e.g. cycle times, to base continuous improvements.
- Enhancement of the operator through letting him/her focus on the work that he/she can do best.
- HIRC is in line with industry 4.0 and the initiatives and research going on both in Sweden and abroad. This can be seen as technology is being presented with functions supporting automation. Also, more flexible computer systems that can integrate with tools, and machines are being realized which could make a HIRC even more efficient.

HIRC is something that could be used in manufacturing industries to increase efficiency and decrease costs, if implemented properly at the right places. The prerequisites found in this report can be used as guidelines to investigate if stations is suitable or not.

7
Future Work

To fully understand the potentials and applications areas of HIRC more research should be done. Some examples of areas where the authors think further research is extra important is described in this chapter together with the recommendations for GKN.

7.1 Recommendations for future research

In this thesis prerequisites for implementing HIRC has been developed. The next step in the processes of evaluating HIRC as a concept is to know how to implement the technology, test it, and evaluate the benefits. A more supported general method for how to implement HIRC would be of big use for companies. A good way to test HIRC is to make a conceptual model of a station in a lab and see how a operator would react and feel about the collaboration[51]. The usability could then be tested and evaluated.

More evaluation of the benefits of HIRC in other industries is also a suggestion for future research. Application areas in other companies in other sectors, industries as well as service sectors could be researched with a similar method as the one in this report to evaluate the prerequisites and benefits.

To make HIRC work in a flexible way, an interface between the human and the robot needs to be developed. This interface must be easy to use but at the same time be advanced enough to handle all the different scenarios that could emerge. Future research is therefore needed to develop a software able to handle these tasks.

7.2 Recommendations for GKN

The findings from the case study showed that there were great potentials with HIRC at GKN. When evaluating design changes the developed check-list could be used to see if HIRC could be a possible solution at a station. The same evaluation methods (interviews, observations, ergonomic analysis, frequency study) used in this report could be used to evaluate another station for GKN. Since there are many similar inspection stations at GKN the developed concept and function description could be used as a foundation to build further on.

From this analyse the authors found that the biggest potentials for improvements when using HIRC would be at stations with a lot of manual work tasks and little control over the work tasks. For those kinds of stations a robot program can be used to standardize the work and benefits from standardized work and continuous improvements can be gained.

Since GKN is part of the VVHIRC-project there are great potentials for the company to impact the development of the software and be one of the first companies to use it. Some recommendations have already been given to the developers from the authors but when the next test release is finished GKN could do more tests of the pilot station in the software. This could be both to understand more of the benefits that could come from HIRC and also to make sure the software have functions that are supporting the aerospace industry and the certain requirements at GKN.

It is also interesting for GKN to start investigating the opportunities of HIRC since industry 4.0 and ongoing research will make the technology more available. Better and cheaper technology will lead to that even more benefits can be seen from the technology and to be ready to use new technology when it is launched can lead to great competitive factors.

However, one of the great improvement potentials found in the case study was the information flow and the IT-systems. To reduce the time spent in front of the computers one first step could be to use a new software for instructions and reporting. To decrease walking at the station the software could be used on handhold computers or computers attached to the operators' arms to make reporting and reading instructions more effective. To start with a better IT-system with more information and a higher level of cognitive automation could be a first step towards HIRC.

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A

Appendix

A.1 Interview questions for operators

- What different tasks are being performed, how does the tasks differ between different products?
- Are there tasks that are crucial for the assurance of the quality?
- Are there tasks that can be hazardous during to risk of getting pinched, dangerous operations, hazard chemicals or heat exposure e.g.?
- Are there heavy lifts that can endanger the safety of the worker or the product?
- What fixtures are used, how do they look and how do they change with the different products processed?
- What tools and machines are used today?
- How is the inflow and outflow of materials and products designed?
- Psycho social factors, does the operator feel good about the job today?
- How is maintenance performed?
- Is it a lot of down time at the station? What is the down time due to? Machines, material, man, method?
- Do you always know what to do with products?
- What is hardest, (to understand? to perform?)
- What is easy?
- What is boring?
- What is fun?
- What takes additional time?
- What can go wrong?
- What can differ? Material, method, man, machine? Something in the inflow outflow?
- When do you get stressed?

B

Appendix

B.1 Ergonomic evaluation methods and standard at GKN

GKN has its own Standard regarding ergonomic requirements for work tasks. The document conforms to the European Council Directive 90/269/EEC. The GKN document also includes additional demands from Swedish Work Environment Authorities provisions in AFS 2012:2 regarding Ergonomics for the prevention of musculoskeletal disorders. It also refers to Swedish Work Environment Authorities Organisatorisk och social arbetsmiljö. AFS 2015:4 and Arbetsplatsens utformning. AFS 2009:02.

The standards includes measurements of the desirable work postures and what postures that should be avoided. There are also regulations on how long periods certain positions should be aloud to occur during a working period. Figure 4.1 shows an example of three different areas. The green is the area where you want to work and the red is the least desirable positions are, referred to the position of the hands. There are high risk for injuries when the hands are in the red areas over 2 hours or above 100 times per day.

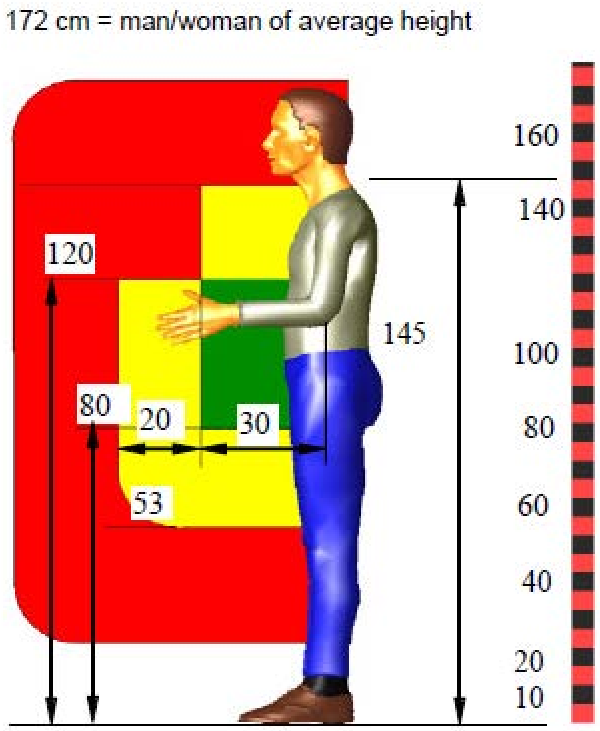

Figure B.1: Recommended working position for hands in standing posture

There are more examples like this such as considering the positioning of the head, bending and turning of the whole body and more. The figures below shows with color what areas that is preferable and not. When an ergonomic evaluation is made, these images will help to identify working positions that are less desirable.

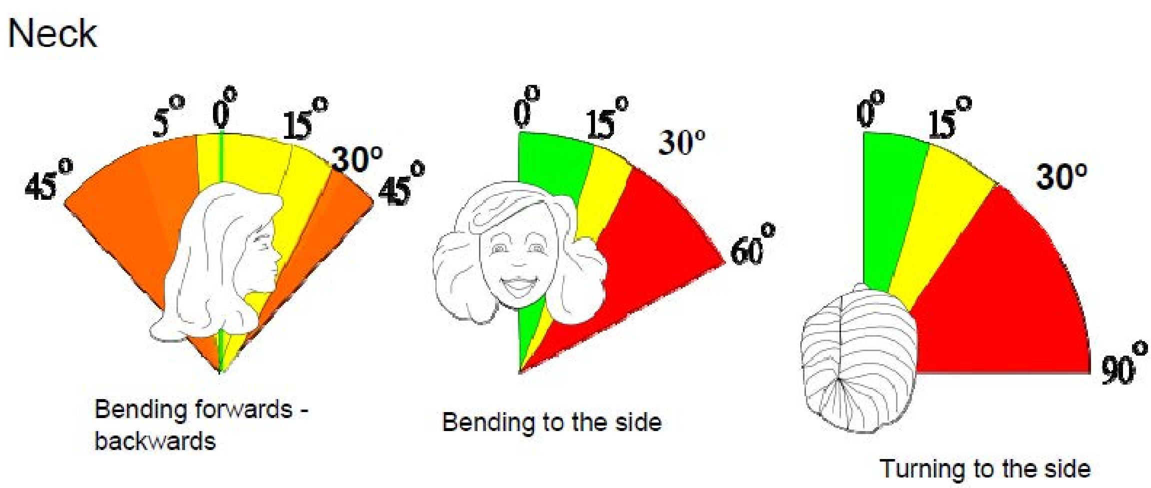

Figure B.2: Recommended working position for the head

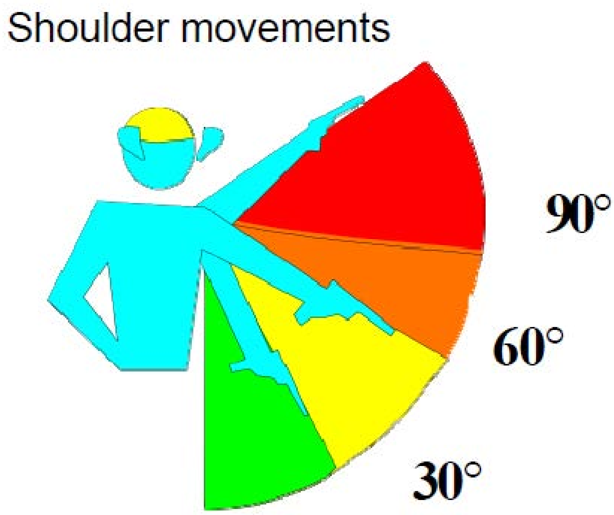

Figure B.3: Recommended working position for shoulder angle

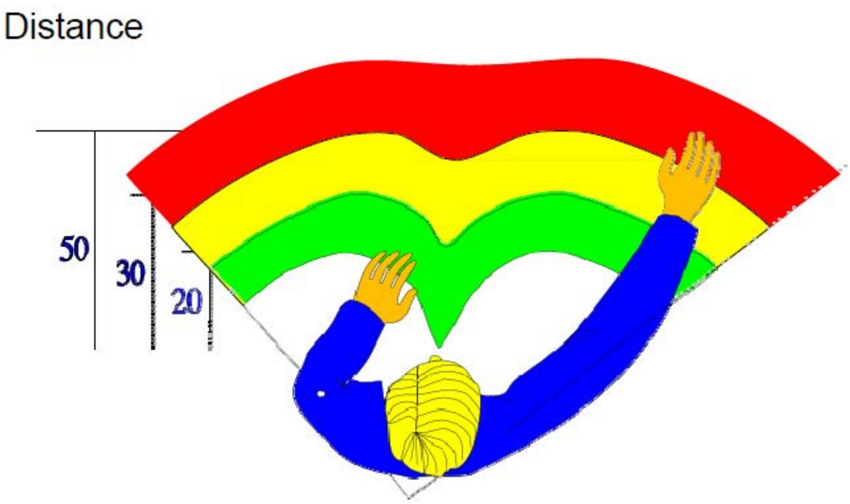

Figure B.4: Recommended distance between body and working area

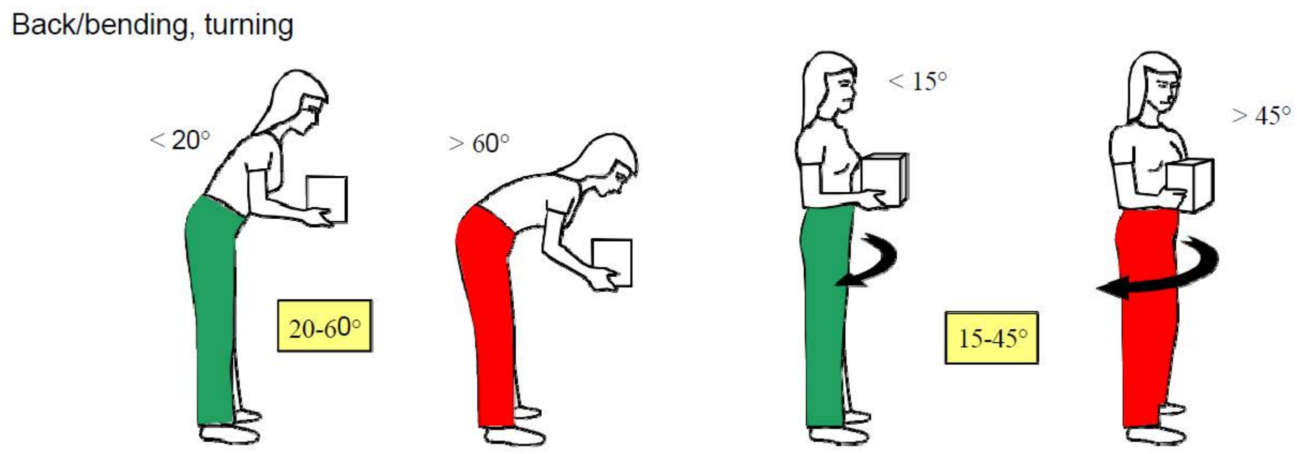

Figure B.5: Recommended angles for bending and turning of the back

This GKN standard also includes chapters about how work enlargement and job rotations should be planned and applied. The social and psychological aspects is also considered. The goal with the standard is to get the staff committed to the work and that none should get sick due to the work.

C

Appendix

C.1 Future state at Inspection

This chapter contains suggestions on how the investigated station, the Inspection, can be developed in a future state using HIRC. First resourses and the design of the station is described followed by a evaluation of the concept.

C.2 Technical Design and Resources

This section describes how a possible future state of the Inspection could look like. What resources it would need and how it could look like.

- Robot
  A robot that can pick up the material from the pallet, present the material in the correct way according to the program and the preferences from the operators and then be able to put it back in the pallet. The robot should have enough strength and reach-ability to be able to handle the details in a good way. An industrial robot is a must since it is reprogrammable and can be integrated to a larger system connected to sensors and computers etc.

- Sensors
  A camera will be positioned above the boxes where the robot will pick up the parts. The camera will detect how the part is positioned in the box to make it possible for the robot to pick it up.

  The station will be divided into 3 zones where the robot can move in different speeds and these zones will be controlled by sensors.

  The first zone should be where the robot is picking up the material. In this zone the robot should be able to move fast and there should be no access for the operator to this zone as long as the robot is in working mode. The second zone should be where the robot moves the material from the box to the working station of the human. In this zone there should be sensors that makes sure that there is no human interfering in the path when the robot is moving the object, if so the robot should stop or slow down. The third zone should be the collaborative workspace where the human and the robot is both moving. In this space the robot should move very slow and the movements should be controlled by the human and also enabled to stop fast, for example by touching the robot. The robot should only be able to move in the common workspace if the movements are small. For bigger movements, for example turning and showing the opposite side of the product, the human should take a step away and let the robot first move out of the common workspace and move back before going back to work.

Sensors could also be placed by all of the tools used by the operators. The sensors will register whenever a certain tool is taken or if it lays in its dedicated spot among the other tools. Pick-to-light could also be used here to localizing the right tool fast. The robot could also pull the detail away if the sensors registered that the wrong tool was taken.

- Tools

The tools that are used today could work in a future state of the station as well. Optimal would be two dedicated tool wagons, one for each station with a dedicated spot for all tools. This would lead to optimal efficiency since each station could have the equipment close and no waiting time for tools would be needed.

Another solution would be to use the new generation of connected tools. These kind of tools could be directly connected to the software and measurements could be imported wireless to the control sheet without any typing from the operator. When using these kind of tools there are also possibilities of increasing the level of cognitive automation through letting the tools communicate with the workpiece on where to be used etc.

- Employees

In the current state a lot of time spent on administrative work foremost and very little on actual inspection. In the future state there will be a big reduction of the required time for administrative work since the system will present all information for the operator by itself. Material handling will also decrease significantly since the robot will do most of it. The labeling is to be outsourced outside of the the station which will make the operation time decrease even more. Rest of the operation will probably stay about the same. All of these reductions would give a result looking like the graph below.

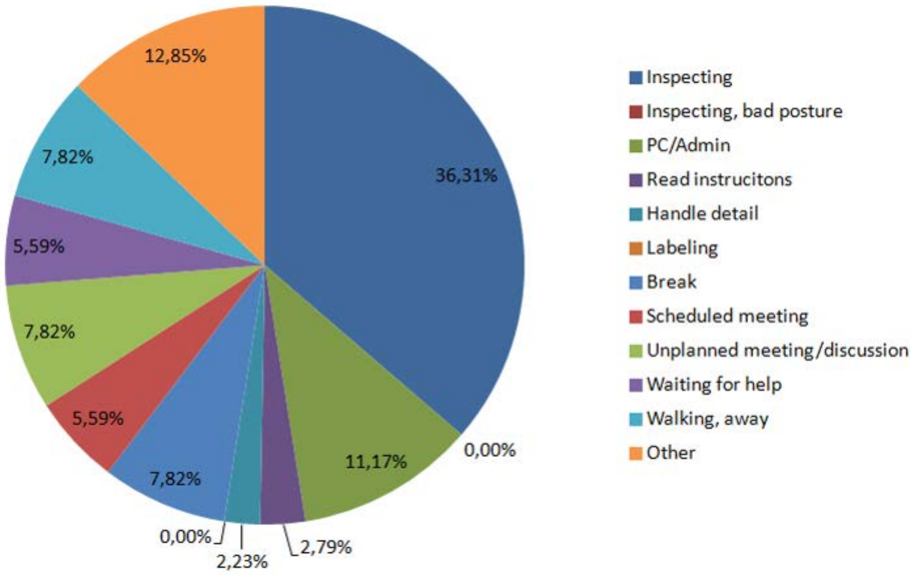

Figure C.1: Future state task devision

In the current state 323 measurements was made, relatively only 171 is needed to fill the tasks in the future state. This will make the total time needed decrease by almost 40%. Therefor, in the future state, only 6 operators will be needed instead of 8 as it is in the current state. The work needed will decrease with 40% and the work force with 25%. Only 5 operators should be needed but a big safety margin is added here since the future state is not evaluated in any larger extent. The operation time will be decreased but to decide exactly how much will need further analyzes.

- Computer system and interface

The fourth part of the system is the information system that gives the operator instructions and information for the different inspection tasks.

For the whole inspection process to work smooth, the interface has to be simple and effective. Operators should be able to learn it and feel comfortable with it fast. Before the operator starts using the interface the robot should have picked up the detail so that the system knows what product it works with. The beginning of the user interface process could look something like this:

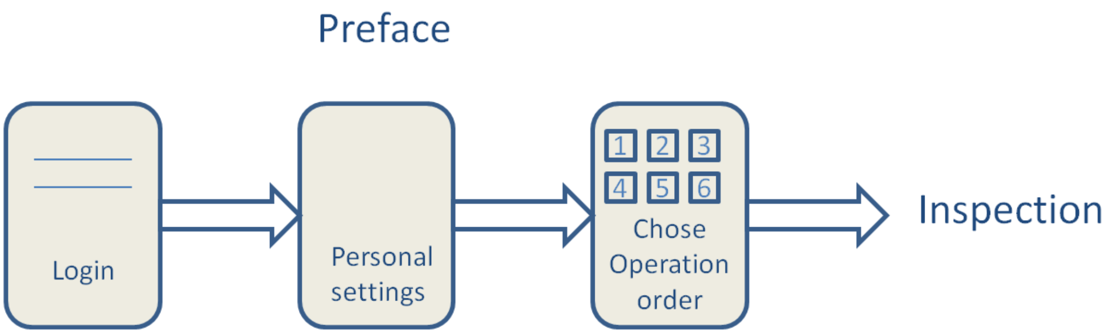

Figure C.2: Preface in the HMI

The log in procedure could be done in many different ways. It could be done by using a RFID-card. One other way is to use fingerprint to log on which also would be fast and reliable. The simplest procedure to implement would be to use the same way as today, to log in with user-name and a password.

When the log-in procedure is done, the next step is to enter personal settings. Most of the personal settings as the height of the operators should already be programmed into the system. Here the operators should be able to choose if they want to sit or stand in the next operations.

On the third screen the operator gets to choose what operation to do and in what order. All of the operations will placed in blocks where the operations fits together. Either that the same tool is used in all of them or that the operations is carried out close to each other on the detail.

When these steps are completed the system goes into the Inspection state. The robot will move the detail into the first position in the first operation and the screen will give the operator new information. First, the program on the screen will tell the operator what tool to use, how it looks and where to find it. When the system registered that the operator has taken the tool it continues to the next screen.

The interface between the operator and the robot will be a combination of these two varaiants of human-robot collaboration;*Speed and separation monitoring* and *Power and force limiting by inherent design or control*. In most of the work tasks the robot will work in the first of the two modes. In some of the operations it would be beneficial if the robot were aloud to move while the operator was in contact with the product. These operations can be that the operator uses his hand and strokes it along the detail to feel the surface. It would therefore be beneficial if the robot were able to move the product while the operator held his hand unto the product.

Layout and logistics

For the logistics it would be best to have the details delivered where the robot could reach them, both pick them up when a new operation starts but also to leave them for the trucks to come and pick them up again. Preferably there should be at least two spots for each robot, one for incoming and one for outgoing details. This will minimize the material handling and make the material handling inside the station none.

However the operators will still need to use the manual pallet lifter to transport the pallet to the assembly and back between operation x and y.

Figure C.3: Conceptual model

Figure C.4: Conceptual model.

C.3 Evaluation of future state

This project had a time limit and the main focus was to investigate the possibilities of a HIRC at GKN aerospace and not necessary develop a design ready to install. Due to this the specifications and exact design/layout of the future state of the station has not been worked through. To go from ideas and function requirements to a final station ready to install is a lot of work and usually those kind of projects are done by a supplier at GKN. When the group responsible for installation of new machines and robots at GKN was interviewed they made clear that stating functions, most important requirements and do some initial drawing of potential layout was often good enough as pre-work before a company specialized in industrial installations could take over and finalize the idea.

Since the analyze of the station in this project was done mostly to test and evaluate methods the step of involving a supplier and asking for offers and prices has not been done and therefore a final cost analysis is not possible to do.