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Movable Automation for Low Volume and High Mix Production – Benefits and Barriers

Master's thesis in the Master's Programme
Production Engineering

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Abstract

The current trends of mass customization along with digitalization of the industry are increasing the demands on companies to produce low volume series with high variation. Small and medium sized enterprises generally don’t have the financial power to invest in the latest production technology, nor is it plausible to dedicate machines for a few products when these subcontractors’ product range is ever changing. However, the rise of movable automation may be a means for these companies to automate their low volume high mix production. This thesis aims to evaluate the operational effects of this movable automation, but also to find the barriers of utilizing it at three case companies. The movable automation in this study is movable industrial robots with a fenceless security system.

The results show that the case companies have experienced problems with utilizing the robots in a favorable way. Therefore, direct operational effects were difficult to find, but the robot is deemed to have high potential at these companies, decreasing production costs, increasing quality, making the work environment better and increasing productivity. However, in order to utilize the potential that the robot provides, there are barriers that the companies need to overcome. The main barrier being the studied companies’ lack of resources in the form of time and competence. This leads to difficulties of adapting their products for automation, as well as designing and producing grippers. Hence, the robot has not been able to cope with the low volume high mix production of these companies as intended. With enough resources spent on developing the technical solution, it is believed that the companies will be able to utilize the potential of movable automation, thus increasing their competitiveness.

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Kevin Berndtsson & Johannes Christensson. Gothenburg, June 2019

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1. INTRODUCTION

This chapter aims to briefly explain the settings of the project. The reader is supposed to be presented with all the necessary background information of this master thesis, which includes the studied companies, the background to the thesis and the purpose of it.

1.1 Background

For a long time, industrial companies in Europe have been moving their manufacturing operations to low-cost countries. However, the basis for decisions about where to locate manufacturing is about to be changed. Wages are increasing in new emerging economies which makes the cost savings, that formed the decision in the first place, less noticeable (Regeringskansliet, 2016). Bossen and Ingemansson (2016) underline that digitalization and automation will be of great importance to the Swedish manufacturing industry. A higher degree of automation has the potential of making manufacturing industries more flexible, allowing them to produce with higher quality and reduced costs. In the era of mass customization, higher flexibility is especially important to stay competitive. Keeping the jobs in Sweden is crucial, since the industrial sector and industrial services sector are accountable for 77 percent of Sweden's total exports, which is almost half of the total gross domestic product (GDP) (Regeringskansliet, 2016).

Furthermore, the supply of skills must be improved, finding the right person with the proper skillset is challenging for every company and important for competitiveness. In Sweden, the proportion of the population with a science or engineering degree is lower than average in the EU (Regeringskansliet, 2016). Robotics, automation, and additive manufacturing demand new skills which set new requirements to the workforce. A societal and industrial transformation is needed to cope with the challenge. Otherwise, globalization will make the best personnel leave for companies abroad, which will lessen competitiveness (Regeringskansliet, 2016). Moreover, the increased demand of skilled workers and the possibility to outsource low-skilled work, has created a fear of unemployment among European workers (Falk & Wolfmayr, 2008). Industry and research collaboration will be important especially in small and medium-sized enterprises (SMEs) to get access to up-to-date technology and knowledge. Less technologically advanced companies, like SMEs, can benefit from focusing on research and development, with the aim to acquire more advanced technology (Bos et al., 2010). Furthermore, Bos et al. (2010) argues that adapting to technological change is essential for European companies that aspire to grow.

1.2 Problem definition

Production of low volume series with high variety is the reality for a large share of the Swedish industry (Löfving et al., 2018). However, the implementation of movable industrial robots might have the potential to increase both competitiveness and social sustainability in the Swedish manufacturing industry (Regeringskansliet, 2016). The new technology and ability to move an industrial robot might be a solution for SMEs to handle their low volume production with high variety. Traditional automation has mainly been used in high volume low mix production, which is why the degree of automation in SMEs is so low (Löfving et al., 2018). However, with this new technology, the robot could be moved to a machine where a product that is best suited for automated production is being produced.

The movable robot offers an industrial robot that can be moved, is easily programmable and a security solution without fences. One robot could be moved to numerous positions where it is needed the most at the time, realizing a flexible automation solution for different production settings with fast commissioning.

In order to address the implementation of movable robots, a research project called LoHi Swedprod has been initiated. The project if financed by the strategic research program Produktion2030. This report is a part of LoHi Swedprod, responsible for the evaluation of the effects of flexible automation in SMEs.

1.3 Company introductions

This chapter presents the visited companies that have implemented the studied automation solution. Furthermore, a short presentation of the robot provider is also given.

1.3.1 Company Sheet

Company Sheet is a sheet metal subcontractor for customers in various sectors and have less than 50 employees. The ability to offer the customer complete solutions is important for Company Sheet as a subcontractor. The company manufactures over 9000 different components in varying volumes. Competitive priorities are quality, delivery time, flexibility and services. The owners have a long-term plan for investments to stay competitive, including automation strategies. The company has invested in both fixed robots for material handling and automated machines besides the newer flexible and moveable automation technology for material handling. The goal is that one operator can serve two machines with the help of automation.

1.3.2 Company Metal

Company Metal is also a sheet metal subcontractor selling complete solutions to customers in different industries and have less than 50 employees. Competitive priorities are quality, delivery time, flexibility and services. They are process oriented and strive to offer the newest technology to customers. The company has invested in several automation solutions the recent years, both fixed and flexible automation technologies for different purposes. The company offers a wide variety of sheet metal forming operations such as pressing, drawing and welding. The company wants to automate products in their drawing-department. The challenge with drawing operations is that the item will change its form and have to be done in a number of stages, making the shaped item difficult to grasp.

1.3.3 Company Component

Company Component is also a metal subcontractor with 350 employees, with around 50 employees on the site of interest. The focus is to offer customers complete solutions from prototype to finished products for small to midsize series (1-5000). The mission is to enhance their customers competitive strength through their services in metal forming and surface treatment. They want to progress towards more automation to stay competitive in the future, the investment is a step in that direction. They want to automate products in their press brake forming operations in order to reduce workload on the operators since the products are heavy and ungainly to handle for an operator.

1.4 Purpose and goal

The purpose of this thesis is to evaluate the effects that flexible, movable automation have on the production systems of three various SMEs. More precisely, the thesis aims to evaluate the system performances in terms of competitive factors such as cost, speed and quality. The operators' view on how the work environments have changed are also investigated. Furthermore, the thesis also explores the implications of installing and utilizing the movable robots.

1.5 Delimitations

This report is delimited to the evaluation of one specific type of flexible automation and the three companies that have installed it. Hence, this report does not compare the presented automation technology with any competing technology. The three companies are all subcontractors within sheet metal forming, delimiting the study towards SMEs. The ergonomics is evaluated after the robot implementation to evaluate the present state.

2. THEORY

This chapter declares the theoretical framework, which is the basis for evaluating and analyzing the results.

2.1 Manufacturing strategy

Manufacturing strategy has many definitions as strategies change over time, but all definitions have in common that a manufacturing strategy must be aligned with the overall goal of the company if competitive is to be achieved (Dangayach & Deshmukh, 2001). Furthermore, what the companies use as competitive advantages is strongly intertwined with their manufacturing strategy (Netland & Frick, 2016). There are five manufacturing capabilities that need to be prioritized by companies in order to achieve a competitive strategy. Furthermore, by utilizing policies and an overall mission of the company, these capabilities can more easily be achieved (Dangayach & Deshmukh, 2001). These capabilities include:

- Cost: Being able to produce at a low cost
- Quality: Production of high-quality products
- Delivery dependability: Deliver on time
- Delivery speed: Being able to quickly react to customer orders
- Flexibility: Being able to reach to changes in products, product mix or changes in sequence

There is often a trade-off between these capabilities, meaning that companies compete with different capabilities (Netland & Frick, 2016). In order to achieve competitiveness a company needs to make strategic choices in areas such as production planning, product design and other organizational decisions (Dangayach & Deshmukh, 2001). Best practices has gained much attention within manufacturing strategy, it includes optimized production technology, flexible manufacturing systems and lean production among other things (Dangayach & Deshmukh, 2001). More recent competitive factors have arose lately, including sustainability and responsibility. However, according to Netland and Frick (2016) these capabilities are the lowest prioritized by European manufacturers.

Dangayach and Deshmukh (2001) describes the relevance of manufacturing strategies for SMEs and the implications of having a strategy as a smaller company. Because of their dependencies on large-scale companies wanting to use their production sites, defining a strategy might prove difficult. However, due to the small size of SMEs, decision making can often be done more efficiently, as can adaptation to changes in design and processes (Dangayach & Deshmukh, 2001). The weaknesses of SMEs are that they do often not possess the latest technological innovations, as they do not have the same financial strength as larger companies (Dangayach & Deshmukh, 2001). Dangayach and Deshmukh (2001) state that a close relationship between SMEs and the large-scale companies that are utilizing their facilities simplify the formulation of a manufacturing strategy for SMEs.

2.2 Digitalization

Ever since industrialization began, technological leaps have changed the prerequisites for the manufacturing industry in different eras. The main paradigms have been named as “industrial revolutions”. The 1st is the use of machines, i.e. mechanization. The 2nd revolution evolved the machines through the use of electricity. The 3rd revolution introduced computer technology and electronics to the manufacturing industries (Lasi et al., 2014). These revolutions have all enhanced the ability to produce material goods with higher efficiency than the era before. The era of today has entered the 4th industrial revolution, named “Industry 4.0”. The goal of this era is to use digitalization and utilize new technologies to transform industrial manufacturing to enable flexibility in production systems (Rojko, 2017). During these paradigms, the trend in manufacturing has shifted from mass production to mass customization. Where focus has shifted from manufacturing high volumes with few variants to low volumes with many different variants as can be seen in figure 2.1.

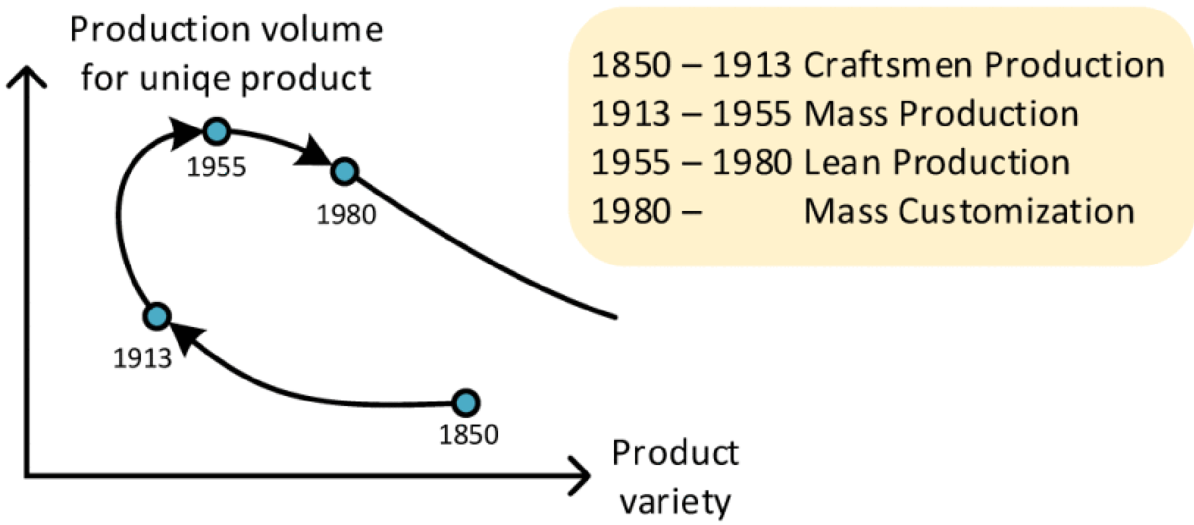

Figure 2.1. History of Mass production by H. Yetiş & M. Karaköse (CC BY-SA 4.0)

The term digitalization refers to a process of change driven by technology. Technology progress and digitalization offer new possibilities to increase mechanization and automation in manufacturing. More technical aids will be available and used which will support physical work (Lasi et. al., 2014). Different sectors will face different challenges when doing a digital transformation. Due to the variety of areas within the manufacturing industry, there is not a template for how companies should handle digitalization (Bossen & Ingemansson 2016). Successful implementation of digitalization in the industry will enhance companies’ competitiveness and offer new business opportunities with new products, processes, and services (Bossen & Ingemansson 2016). For example, a higher degree of automation in manufacturing could enable more flexibility in processes and new ways higher quality and lower production costs (Bossen & Ingemansson 2016).

2.3 Automation

Automation has undergone an evolution where the focus has shifted from fixed industrial robots with an inability to adapt to variability to be flexible and easy to change to different products as well as processes (Miller, 2017). The traditional automation was designed to produce a few or only one product types in large batches. While the demand was high, fixed automation could prove itself both efficient and relatively cheap (Kurfess, 2004). However, as soon as new products were to be introduced or if the process itself needed to change, fixed automation would prove difficult to adapt (Miller, 2017). The next step in the evolution of automation is programmable automation (Miller, 2017). This kind of automation is designed to be able to adapt to changes in a production system, a new code can be written (Deb & Deb, 1994). However, programmable automation still requires a manual changeover, which means that a changeover requires downtime. The last step of the evolution is the flexible automation, which can easily change between different product types without needing a significant amount of downtime for manual changeovers or time-consuming code writing (Miller, 2017). Utilizing flexible automation in an environment with a high mix of product types could, therefore, prove extremely cost-efficient, while the same goes for fixed automation in an environment with low product mix (Miller, 2017).

Automation has a huge potential as machines are surpassing human workers in several work tasks (Manyika, 2017). Hence, it is no surprise that automating work tasks will impact productivity but also the economy of the businesses that automate their processes. Manyika (2017) estimate that automation could raise productivity growth globally by 0,8 to 1,4 percent annually, much due to reduced error frequency, quality improvement and speed improvement that automation may result in. Moreover, about 60 percent of all professions consist of at least 30 percent of activities that are possible to automate (Manyika, 2017). The tasks that are most prone to become automated are physical work tasks in structured and predictable environments, such as jobs in manufacturing, but also collecting and processing data. However, while work tasks are automated, the need for new occupations that were not foreseen will most likely arise (Manyika, 2017).

2.3.1 Effects of automation

Automation may have a significant impact on a production system's performance, e.g. the productivity, quality and cost. This chapter aims to present automation's effect on these performance objectives.

Cost: Automating processes has for a long time been a method for companies to reduce production costs (Yongjun Choi & Baker, 2017). Historically, automation has been used to replace operators, which has lowered costs as wages have been eliminated (Yongjun Choi & Baker, 2017). In fact, automation can be more cost-efficient than employing even the lowest paid workers in the world (Yongjun Choi & Baker, 2017). Furthermore, as labor costs are increasing and the cost of robots decreasing globally, the cost-efficiency of robots will increase relatively the cost-efficiency of human labor (H. Kihlman, 2018). Yongjun Choi's and Baker's (2018) study show that automation is crucial for Korean companies to stay competitive, due to an aging population and the increasing labor costs. Furthermore, Tracey et al. (1999) found a correlation between several competitive factors and the usage of advanced manufacturing technology. Among these competitive factors were the capability to deliver and the price that could be offered, proving that automation can indeed lead to cost-efficient production.

Quality: Bergman and Klefsjö (2010) define quality as “The quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customers”. Hence, quality is decided by the customer and may very well lead to a higher profitability and productivity if a customer chooses to return. Therefore, not being able to deliver what the customer wants may be costly in several ways, for example, by having to do rework but also by losing customers (Bergman & Klefsjö, 2010). Work tasks in manufacturing companies are often repetitive and monotonous, which is why automating these tasks may improve quality, as robots don’t tire. Case studies confirm that automation improve quality, for example in Australia’s mining industry the quality of the extracted coal increased by automating the mining process (Mundry et al., 2015). Bossen and Ingemansson (2016) argue that automating and digitalizing of manufacturing processes is necessary to make Swedish industry competitive. One of the competitive factors that will increase is quality, since robots can be programmed to perform the same tasks for an entire working day without wearing. By being better than humans when it comes to both repeatability and accuracy, quality of processes will increase and consequently the quality of products (Bossen & Ingemansson, 2016).

Speed: Industrial robots are widely used for their speed in performing several manufacturing processes, such as welding and cutting operations (De Backer et al., 2018). Furthermore, robots might not be able to perform every task faster than a human operator, but they can still increase throughput and productivity as they can potentially work 24 hours per day. An example of a speed increase comes from Boeing’s jet assembly plant in Everett, where painting robots have reduced the process time of painting a wing from four and a half hours to 24 minutes (De Backer et al., 2018). Furthermore, due to the increase in all these competitive factors Graetz and Michaels (2018) found that robots do help companies increase their productivity, wages, while also reducing costs of products.

2.3.2 Human perspective on automation

Human Centered Automation: Increased complexity in engineering together with mass customization requires productions to manage high flexibility, small batch sizes, small product volume and a high number of variants. All of these also needs to be done at a low cost. The human worker is a central part of this since humans are flexible and can handle challenging tasks (Mattsson et al, 2014). It is therefore important to keep the human in mind when the technical environment progresses and mind the social sustainability aspects of the workforce like aging, skills, and health (Mattsson et al, 2014). The human is still a vital part even in the most complex systems since automation itself may fail, humans have become the monitor of automation. Human centered automation has come to be seen as the proper approach to evaluate the allocation of tasks between human and automation (Sheridan, 1995).

According to Thomas B. Sheridan (1995), HCA is purported to mean:

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(s).
10. Achieving the best combination of human and automatic control, where the best is defined by explicit system objectives.

These objectives altogether cannot be fulfilled, some may be unwanted and/or in contradiction with each other (Sheridan, 1995). Meaning that there is no "right answer" for every case, more of a guidance and food for thought to consider different aspects when making decisions about automation.

Automation could be defined as a process or procedure executed by a machine agent, once performed by a human (Parasuraman & Riley, 1997). In many fields of work, like manufacturing and aviation, both physical and cognitive functions have freed the human from demanding activities. Humans are essential in all systems (planning, creative thinking, decision making), but usually a greater emphasis is taken on technological aspects and human aspects of automation are set aside (Parasuraman & Riley, 1997). It has become evident over time that automation changes human activities, sometimes in ways unforeseen by system designers, leaving the human operator to manage the resulting system.

Human and automation: Parasuraman & Riley (1997) apply the terms; use, misuse, disuse and abuse to describe different factors influencing humans with respect to automation technology. *Use* considers the human operators' ability to choose activation or withdrawal of the automation, affected by factors such as trust, mental workload and risk. Each of those factors being perceived differently by individuals (Parasuraman & Riley, 1997). *Misuse* considers overreliance on automation, affecting monitoring or decision biases of the human operator. Operator workload, automation reliability and automation consistency are factors affecting the monitoring as well as automation state indicators (Parasuraman & Riley, 1997). *Disuse* considers neglecting or underutilization of automation, which is affected by false alarms. *Abuse* considers the human performance to be overlooked by system designers and managers, which in the end can lead to further misuse and disuse of the automation by the operator (Parasuraman & Riley, 1997).

Use of automation: Humans' attitudes toward the use of automation vary extensively between individuals, making it difficult to envision someone's attitude even if questions are asked directly. Proven reliability or accuracy of the automation may not always be enough to foresee the usage of automation by a human operator. Thus, it is important to understand what aspects, both positive and negative, that affect the human use of automation (Parasuraman & Riley, 1997). Mental Workload is one of the major reasons in acquiring automation, by reducing the mental workload the chance of human error becomes lesser. Although, that is not always the case, studies show that there is individual variability in the way people perceive automation (Parasuraman & Riley, 1997). The knowledge of the individuality may still be useful since an evaluation can be made on the scenarios before-and-after (Berlin & Adams, 2017). Cognitive Overhead is related to workload, referring to the decision to use automation itself. The advantage the automation offers may not always be evident at first, if it requires much thought and evaluation in order to see the benefit, then the cognitive overhead may influence the operator not to use the automation (Parasuraman & Riley, 1997). If the task can be performed manually, the aid offered by automation must overcome the cognitive overhead perceived by the operator. A high level of workload on the operator may affect the operator's time and ability to use the automation even if the automation is reliable and accurate (Parasuraman & Riley, 1997). Trust often influences the use of automation. The factors affecting trust in automation are resembling factors for interpersonal trust, reliability and honesty, which are essential factors for automation as well. The opposite occurs when the operators are let down, regaining trust takes time but is affected on the attitude of the operator. Occasional failures may not affect trust considerably, but preserved failures may affect trust (Parasuraman & Riley, 1997). Experience will lead to that breakdowns and bugs becomes present, the user will then develop workarounds and make the work inefficient. The only form of trust in automation that is immutable is negative trust. People are certain that any machine will fail to work properly (Hoffman et al., 2013). New technology in the workplace usually don't gain full acceptance from day one, operators often need to adapt to the new conditions and before the automation earns the trust.

Trust in automation: Trust is vague and very interpersonal between humans, put automation in the equation and it becomes more complex to analyze. Studies have shown that more complex technologies with autonomous systems increase the need for expertise from operators rather than reducing it (Hoffman et al., 2013), making the operators trust in the automation a subject matter. Perceived competence, benevolence, understandability and detectability are some of the factors deciding interpersonal trust in given situations. These factors are also present in trust in automation (Hoffman et al., 2013). Add to that, reliability, validity, utility, robustness, and false-alarm rate. Those factors are all related to shortcomings and limitations in technology. Just like interpersonal trust, trust in automation may also be lost and difficult to re-establish (Hoffman et al., 2013).

Misuse of automation: Misuse of automation can be present in different ways, either by mistrust but excessive trust may also be present. Operators may not bother to notice alerting systems as signs of mistrust or the operator confide the automation too much, not recognizing constraints or failing to monitor the automation accordingly. Both operator and management may show signs of overreliance by expecting the automation to monitor or resolve tasks that it cannot (Parasuraman & Riley, 1997). Inaccurate decision making caused by biases and monitoring failures may be consequences from overreliance. If the operator's attention is occupied by another task, detecting automation failures becomes difficult for the operator, which make it important to have salient state indicators (Parasuraman & Riley, 1997). Regarding disuse of automation, the frequency of the alerting system must be set at appropriate levels by the system designer. Meaning that the false alarm rate is not too plentiful, since it could be the cause of gained mistrust in the automation by the operator, leading to them not caring about safety signals. It cannot be too scant either, on the expense of safe condition (Parasuraman & Riley, 1997). Abuse of automation considers built in faults by designers and implementation by managers which affects the operator performance in a negative way.
Generally, acquisitions in automation has been technology-centered in its approach, making the operators interest subordinated to the automation (Parasuraman & Riley, 1997). This approach often leads to that operators are left with leftover tasks that the automation cannot cope with, i.e. ironies of automation (Bainbridge, 1983).

Ironies of Automation: Even though automation is brought into an industrial process to ease the work for the operator, it may expand the problems rather than exclude them. The classical way of thinking regarding automation is to replace the human entirely and hand the tasks to automated devices. That is not the case, even highly automated systems needs human for supervision, monitoring and maintenance to name a few tasks (Bainbridge, 1983).

One of the most evident ironies is the tasks that the automation cannot perform, the human operator still needs to handle the leftover tasks. Another irony is the built-in shortcomings from designers. The human operator may be seen as untrustworthy and ineffective from the designer's eyes and therefore try to eliminate the human from the system which instead can cause operating problems. The combination of these ironies gives the human operator a collection of arbitrary tasks, and possibly not the right support to perform them (Bainbridge, 1983).

2.4 Flexible automation

Utilizing automation in small and medium-sized companies has traditionally been hard, due to the significant amount of time needed for changeovers, that the high product variation and small batch production brings (Löfving et al., 2018). Traditional automation, which is fixed and designed for environments with low product variability and high-volume production, is not suitable for these smaller companies. However, Löfving et al. (2018) have identified what requirements there are on flexible automation for small and medium-sized companies.

Material handling: Flexible automation needs to be able to handle the material going in and out of the machines. Furthermore, automation should be able to do this without any human interactions.

Easy programming for operators: With a high product mix and small batch production, the automation will inevitably need reprogramming between every batch. Therefore, it is crucial for automation to easily be reprogrammable.

Mobility: The companies studied by Löfving et al. (2018) all had batch production layout and machines dedicated to certain processes. Hence, machines could be situated far from each other, which caused the need for movable automation. Furthermore, the automation should be possible to move manually between machines. When connecting a robot to a new machine for the first time, a risk analysis is necessary and the entire solution requires a CE-certification before production is allowed to start (Arbetsmiljöverket, 2015). Hence, the movability may require a numerous number of CE-certifications depending on how many machines the robot is connected to.

Safety solutions: These small and medium-sized companies sometimes produce very small batches, in which cases producing these batches is more efficient with an operator manually operating the machine instead of reprogramming the robot and have it do it. Hence, being able to access the machine without any safety fences around the automation technology is a requirement.

Payload: The studied companies had requirements on the technology's ability to lift products. They required it to be able to lift heavy objects with a weight of more than 10 kg and ungainly objects with shapes that are hard to lift. Moreover, the grippers need to be able to handle a large variety of products of different shapes and weights. The size of the grippers needs to match the size of the metal sheets that the companies are using. If a gripper is too small, the metal sheet might begin to wobble and become a danger or create problems in the manufacturing process. Hence, being able to reconfigure the grippers could be a solution.

Movable automation: offers the opportunity to relocate the automation. The robot, in this case, uses docking stations that are installed next to the machine or task where it will operate and is moved either with a forklift truck, pallet truck or driverless transport vehicle. One robot could be moved to numerous positions where it is needed the most at the time, realizing a flexible automation solution for different production settings. Furthermore, the fenceless security solution simplifies the movability further since additional security elements are not needed. Instead, it uses laser sensors that sense the space around it. If a person enters the robot-zone it will firstly slow down and then stop if something or someone moves very close. Solutions without fences already exist in the form of collaborative robots. There are different safety solutions for collaborative robots, but they are similar to the solution of movable automation, with the robot slowing down when an operator is getting close or stopping when the operator is too close (Fryman & Matthias, 2012). It is also possible for the collaborative robot and operator to have contact, but with the robot's force being limited. However, the studied movable automation is a conventional industrial robot and not a collaborative robot, allowing the companies to use the benefits of industrial robots together with different machines. Finally, if the flexibility that the movability provides is to be efficient, the programming of the robot needs to be simple and relatively fast, as Löfving et al. (2018) stated.

2.5 Production economics

Production is the process of refining inputs and to transform these into an output that can be sold for profit (Rasmussen, 2013). While discussing production, it is important to consider economies of scale, which describes how much production increases when a company increases all their production inputs. (Rasmussen, 2013). Therefore, by having a larger production, the fixed costs of a company will be distributed among the increased amount of produced output units. Another way to reduce the fixed costs is by increasing productivity, which can be explained as the relationship between output and input, where an increased productivity means that more output will be produced per input unit (Rasmussen, 2013). Hence, productivity is a competitive factor for manufacturing companies in high-cost countries. There are different ways to reduce the cost per unit, for example by utilizing the capacity better or by investing in new technology that might work faster and at the same time free operators (Rasmussen, 2013).

Another way to reduce the cost per produced unit, especially in an environment with high product variety, is to reduce changeover times (Ulutas, 2011). In fact, short setup times are crucial for companies that produce low volumes with high variations. With a shorter setup time, the cost for each produced unit will decrease, enabling low volume and high variation production (Ulutas, 2011). Hence, a company cannot produce smaller batches than the changeover times allow.

2.6 Production ergonomics

Ergonomics is a wide term, which can mean anything from physical activities to the understanding of instructions (Berlin & Adams, 2017). Just like a machine in a production system wears over time, people do too. Focusing on production ergonomics is a means to proactively counteract the risks of employees getting musculoskeletal disorders (MSDs), causing pain and discomfort (Berlin & Adams, 2017). The International Ergonomics Association (2000) defines ergonomics as: "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance."

In accordance with IEA's (2000) definition, production ergonomics is used to enhance both human well-being as well as the performance of the production system. In an environment where ergonomics is not emphasized, the performance will consequently be worse. The physical health will be affected by the ergonomics, which in turn affects the human's ability to work (Berlin & Adams, 2017). Physical health issues may be ignored for some time but will eventually force work-related musculoskeletal disorders and sick leaves (Berlin & Adams, 2017). Except for the obvious negative effects on the employees, sick leaves will also affect the company. A sick leave brings several expenditures, such as the company having to compensate the employee on sick leave, but also recruiting of new personnel along with the loss of quality and productivity until the new employee has been fully trained (Berlin & Adams, 2017). MSDs are actually the cause of half of the absences from work and cost the EU €240 billion each year (Berlin & Adams, 2017). Of these sick leaves, blue-collar workers are the majority, especially machine operators and similar professions (Berlin & Adams, 2017). The physical loading that may cause MSDs consists of three factors and their interplay, they are posture, forces and time (Berlin & Adams, 2017).

Posture: A posture is how the body is positioned and aligned, which is controlled by the body's muscles working to preserve a certain position (Berlin & Adams, 2017). Good posture is defined by Berlin & Adams (2017) as where the body is optimally positioned to execute a given task, for example by having a symmetrical distribution of forces on the body and keeping balance. Bad posture, however, is the opposite. A position where the body tissues are exposed to physical loading but don't need to be (Berlin & Adams, 2017).

Force: Force is divided into different types, that will all have negative effects on the human body if they surpass the body's loading limits (Berlin & Adams, 2017). The different types of forces are dynamic forces that can change in both vastness and direction, static forces that load a certain muscle group for a certain period of time and repetitive forces which is a type of static force. However, instead of loading a certain muscle group for a certain amount of time, repetitive forces put a load on one muscle group but so frequently and without recovery between that they are similar to static forces. Lastly are external and internal forces which are caused by, for example, lifting or maintaining postures respectively (Berlin & Adams, 2017).

Time: Even though loads may seem small, they can still cause MSDs if handled often or for long times (Berlin & Adams, 2017). The time factor regards both frequencies of loads and the actual time a load affects a human.Hence, time is a crucial factor to physical loading.

The interaction between the three described factors may increase the risk of getting work-related MSDs (Berlin & Adams, 2017). Nevertheless, the factors should not be considered harmless on their own, however, lifting heavy weights with a bad posture and for a long period of time increases the risk of MSDs.

3. METHODOLOGY

This chapter presents the utilized methods and strategies for collecting relevant data, to fulfill the purpose of this thesis.

3.1 Research strategy

According to Denscombe (2014), the research strategies must be chosen so that they fit the purpose of the research. As the purpose of this report is to evaluate the effects of a certain type of automation, but also the implications of installing it at different companies, the strategies chosen are case studies and a mixed methods approach.

3.1.1 Case study

Case studies are used to acquire an in-depth understanding of relationships and processes in a specific social unit (Kothari, 2004). The aim of a case study is not only to understand how things work, but also why things work as they do in a certain environment. In this case, the different social units were the three visited companies. The strategy of these case studies is then to firstly understand the effects and implications of utilizing the robot, but then also why the robot has the effects it does and why there are implications with using it. Using different types of data along with several methods is encouraged to provide a holistic view (Denscombe, 2014).

The advantages of using this strategy is that is allows the researcher to have a holistic view over the instances that are studied, but also to gain in depth knowledge of specific factors or phenomenon (Denscombe, 2014). Furthermore, Denscombe (2014) argues that case studies are good strategies to use when the researcher wants to understand how things work naturally within a certain setting. Case studies is a method of testing the collected data and assuring that the collected data correspond to reality (Kothari, 2004).

3.1.2 Mixed research methods

Mixed research methods are used to combine the advantages from both quantitative and qualitative data collection methods, while also limiting the effect of their drawbacks (Kuada, 2012). One of the greater advantages with mixing research methods is that the conclusions and results will be triangulated and thus more accurate (Kuada, 2012). The use of different methods allows for a broader perspective and a deeper understanding than just using one method (Denscombe, 2014). The quantitative data of this project consists of the measurements taken during the observations, while the qualitative data consists of the results from interviews and observations. According to Cresswell and Clark (2011) this study is done with an independent level of interaction between the quantitative and qualitative data gathering. Meaning that the quantitative and qualitative methods are done concurrently and then merged in the analysis to form the drawn conclusions. This research design is also called convergent design, which is beneficial in a study where the purpose is to acquire a more complete understanding of a certain topic (Cresswell & Clark, 2011).

3.2 Interviews

In order to understand the operators' situation, feelings and their experiences, interviews were conducted with the operators at the different production sites. Furthermore, to get an understanding of the intention of the investment, strategic insights and technical aspects, interviews with site managers were also conducted. According to Denscombe (2014), interviews are the right choice for collecting this kind of qualitative data. One-to-one interviews were held with people from each company that was deemed relevant and with enough knowledge of the concerned equipment. The interviews were semi-structured, where a script with questions had been prepared, but the interviewees were allowed and encouraged speak their minds. Furthermore, the interviews were necessary to acquire relevant data, since part of the project was to understand the operators' situation. This method allowed for in-depth knowledge of their perceived experiences regarding flexible automation and its advantages as well as disadvantages (Kothari, 2004). To increase the trustworthiness of the interviews, the interviews were recorded and notes were taken. The topics of the interviews were discussed with the examiner and the project members in LoHi SwedProd, the used interview template and topics can be seen in Appendix A.

3.3 Observations

Observational studies have been conducted to acquire quantitative data used for statistical analysis of the operators' work tasks. A problem that may arise with the use of observations is that different observers may perceive situations differently, however, by using a systematic approach the risk is minimized (Denscombe, 2014). Systematic observations are standardized with the help of observation schedules that contain items that describe what is to be observed (Denscombe, 2014). Furthermore, the observation schedule describes how the items are to be measured, commonly by observing frequencies of events or duration of events (Denscombe, 2014). The included item needs to be selected carefully and be relevant to the cause of the study. Denscombe (2014) suggests that there are four criteria that the included items need to fulfil. These are:

- The items need to be relevant for the purpose
- The list of items should be complete and cover all possibilities.
- The items need to be easy to categorize and not be ambiguous.
- The items need to occur with a certain frequency.

At the different sites, one operator was chosen to observe. The choice was based on several criteria. The main criterion the operator needed to fulfil was experience in programming and handling the robot. Furthermore, the operator needed to be skilled and used to the daily work in the organization. The reason only one operator was followed at the different sites was to see how much the operator could be free from the robot. The observers were positioned so that the daily work would not be disturbed, while maintaining visibility of the entire working area. Some tasks were filmed for further analysis. The observation schedule used for the conducted observations consisted of a list of activities that the operator was expected to do during a normal day of work. The operator was then studied while performing the daily work, in order to see the relationship between man and machine. Furthermore, the aim was to identify how much an operator could be freed and able to do other tasks than the one the robot was instead handling. Hence, each time the operator started a new activity, it was noted on the activity list and the time for it was measured. The observations result in a distribution of activities and times for each activity. However, due to the natural uncertainty of production systems, the observation schedule could not be used in more factories than company sheet, since the robot was not used on the other sites.

3.4 Literature study

A literature study was carried out to acquire deeper knowledge of the many concepts that this thesis aims to treat. The result of the literature study is mainly to be found in the theory chapter and aims to explain the basic knowledge that is required to analyze and evaluate the results. To describe the necessary concepts, relevant course literature was used. Furthermore, new articles and books were obtained via Chalmers library's database and Google Scholar. Lastly, literature was obtained from project members of the LoHi Swedprod project group. The literature from the project group is essential in order to understand the type of flexible automation that this project aims to evaluate, more precisely the article by Löfving et al. (2018).

3.5 Ergonomic assessment

Risk assessment and management tool for manual handling proactively **(**RAMP) is an ergonomic assessment tool developed by Linda Rose and Carl Lind at the Royal institute of Technology in Stockholm in collaboration with the manufacturing industry. Its purpose is to identify the risk of developing MSDs in manual handling work. There are two types of assessments, RAMP I and RAMP II. The method used for this project is RAMP I, which consists of a checklist of yes or no questions that the interviewee is asked to answer. The questions are divided into different subjects, such as postures, repetitiveness, lifting etc. The answers to the questions provide a result, which shows risk levels explained by colors. A green result means that there is a low risk of developing MSDs, grey should be investigated further and a red color means there is a high risk and the task should be addressed immediately. The assessment in its entirety may be seen in Appendix B. Furthermore, to increase the validity and reliability of the result, it's important to interview experienced operators (Berlin & Adams, 2017). This method was chosen in consensus with the other project member of LoHi SwedProd, as it is specifically designed to evaluate manual work in environments such as the visited companies. The results are used to understand and evaluate the work environment of the operators.

3.6 Man-Machine balancing in Avix

To further analyze the observations at the companies, video sequences of the performed work were filmed. The film sequences together with the activity list of the operator were then used to visualize the work through a man-machine balancing. A man-machine balancing is used to show distributions of how long time each task takes for both the machine and the operator as well as the interactions between the operator and the machine (Zandin, 2001). It was used as a tool for analyzing how much time the operator possibly may be disposable to perform work in other machines. The software Avix was used to perform the man-machine balancing. Avix is a software with several different modules for analyzing manual assembly processes through video analysis and motion studies (Solme, 2018). By using the visuals in Avix Resource Balance, an estimation could be made of how much time the operator can spend at other machines.

3.7 Reliability and validity

As stated by Roberts, Priest and Traynor (2006), reliability and validity describe the trustworthiness of research findings by assuring that the data collection methods have been done with a certain quality. It is of great importance that research results have a high reliability and validity, as these results may be accepted as facts. There are different ways to achieve trustworthy results. In order to assure that the results of this study are trustworthy, the gathered data has been sent to the visited companies for validation. Furthermore, the observations were done by two researchers in order to not observe from one perspective.

3.8 Research ethics

In order to conduct ethical research, one must have been given consent from the participants, while also promise the participants confidentiality (Byrne, 2017). In this project, all interviewees from the different companies have given their full consent and have been informed of the purpose of the study. Furthermore, the interviewees and companies are all anonymous in the report, in order to maintain the promised confidentiality.

4. RESULTS

This chapter presents the results from the gathered data from the different cases. The methodology described in chapter 3 has been used throughout. The results are presented per company, with the main topics divided into subheadings.

4.1 Company Sheet

Strategy: In order to stay competitive, Company Sheet always strive to improve their operations as much as possible. Their priorities are mainly quality, delivery time and flexibility. As a part of this, they want to invest in automated solutions that enhance their competitiveness and manufacturing priorities. The flexible possibilities of the automation solution was the reason for the investment of the movable robot, the ability to serve different machines and not occupy space in the production.

Production setting: Company Sheet have decided to use the robot to serve an automatic press brake machine with sheet metal. The ability to move the robot cannot be utilized at the moment, but there are plans to add another docking station in order to utilize the movability. The setup is traditional for an industrial robot, loading the machine with material and unloading the finished goods on a pallet. The regrip-station is used to place the raw material with precision in the machine, a schematic picture can be seen in Fig 4.1.

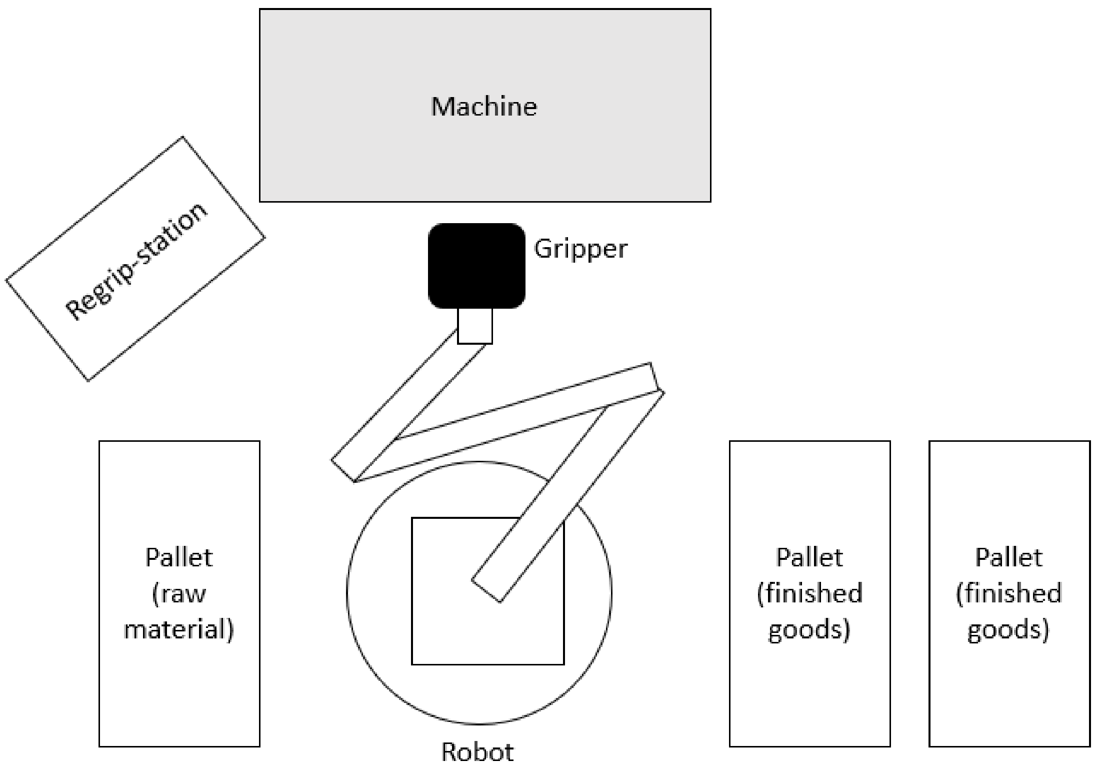

Figure 4.1. Schematic picture of the production setting.

As for now, the robot is used on only one specific recurring order. The order size is around 500 pieces and recur every third week. The quantity of finished goods is somewhat restricted because of the reach of the robot, making the possibility to produce after working hours limited. An operator still needs to refill material and change pallets, approximately once per hour. The programming is not regarded to be a problem for the sake of automating new products, it is fairly quick and facile. From the interviews, it was said that certain adaptations have been made to the working-area, in order to fit the fenceless safety system, e.g. paint on the shop floor and a movable fence to highlight the robot area. This has been done because the area is both a walkthrough area to offices as well as the department for press brake forming. If people go to close the speed will be restricted on the robot. According to an interview, the layout of existing machines might need to change to utilize the robot more, more pallets with finished goods may be possible and to move it away from the walkthrough area.

During the observations, the work during the run of the recurring order were studied. The operator's new tasks were being followed to get an understanding of both how much time that was liberated as well as what tasks the operator did instead. The observed operator was the one with the most experience in robot programming with years of experience of working at the company and in the press brake forming department. It did not take long to change tools and reprogram both machine and robot. Since it was a recurring order, the robot program was recalled from saved runs. Still, some adjustments are always made to ensure the work sequences and the quality. Approximately, it took 20 minutes before the trial run. The operator observed the work for a few cycles to verify that no unexpected errors occurred. Between the batches, the operator had time to work in other machines that had been prepared beforehand. Figure 4.2 aims to visualize the activities the operator was doing, while the robot was working.

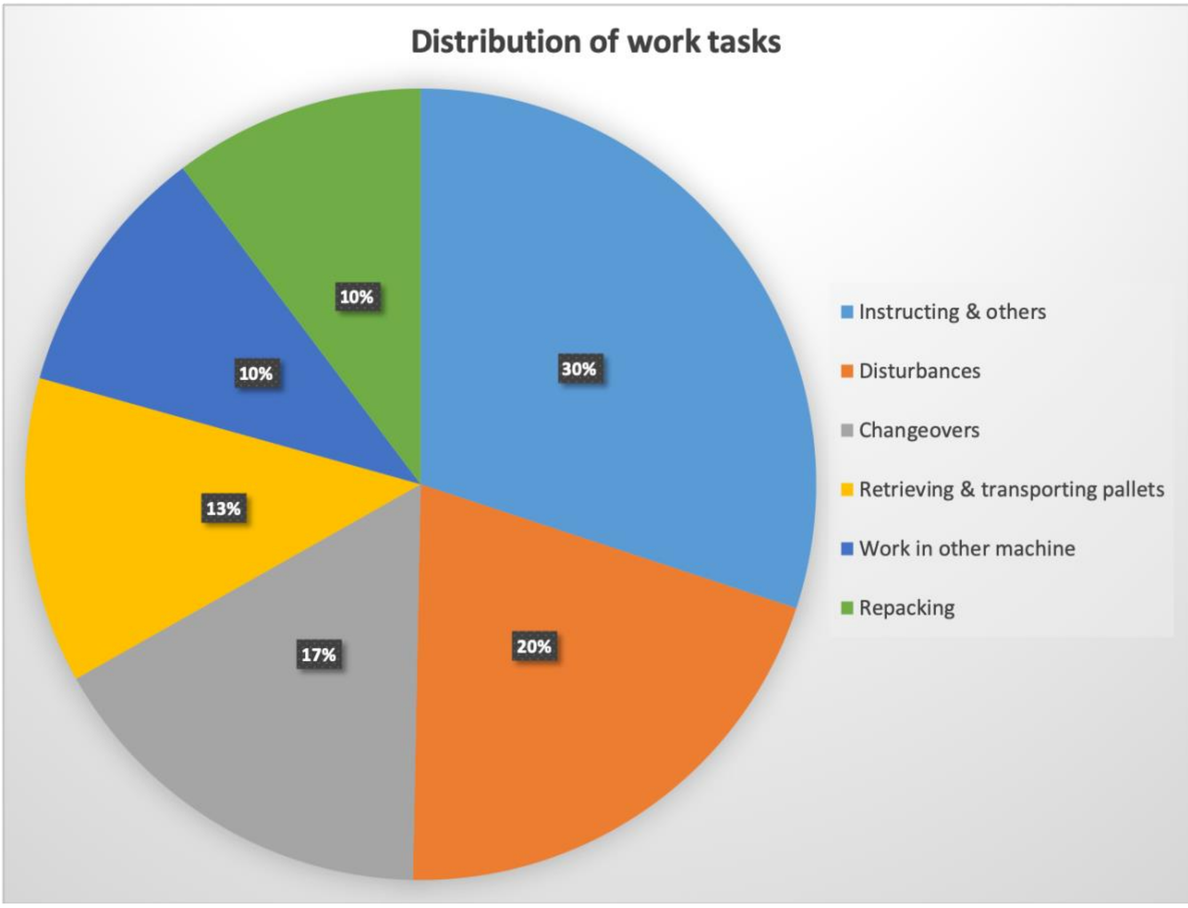

Figure 4.2. Distribution of activities performed by the operator during observations.

The result of the activity list is a distribution of the different activity categories that are performed by the operator during a total of five hours and 30 minutes observation time. The major activities are categorized as *instructing others*, *disturbances* and *changeovers*. *Disturbances* is described further down in the report. One of the other major activities is *Changeovers*, mainly the kind that could not be done while the machine was working. The reason that so much time is spent on changeovers is that the company produce in small series, sometimes as few as one product per order. The *Instructing & others* is the major activity category. The reason so much time was spent in this category can be explained by the fact that the observed operator was one of the most experienced. Hence, if any other operator had any questions they would come and ask him. Furthermore, during the days of observations the operator acted as a team leader, spending time instructing and teaching others how the machines in the press brake forming department worked. The only activities that are directly connected to the flexible robot, except for the disturbances, are retrieving pallets and transporting on pallets. This shows how the operator is able work for a significant amount of time without having to interact with the robot. Figure 4.3 shows the optimal relationship between man and machine.

Figure 4.3. Optimal man-machine relationship between operator and flexible automation.

The picture shows how the flexible robot works on its own for approximately 59 minutes before the operator has to interact with it. After 59 minutes the operator changes the pallets of finished products into two empty pallets. In the picture the time for refilling the pallet with metal sheets is also visualized, which only occurs every other pallet change. After refilling and changing pallets, production can start again. There are still some tasks related to the robot left for the operator to do though. The operator has to repack the finished products, so that they stand upright, into another pallet with pallet collars around it. After these activities, along with some last preparations, the operator is once again free to do other tasks, independent of the flexible robot. The measured times may vary and are to some extent estimations of the reality. Furthermore, the disturbances from figure 4.2 are not included in the man-machine relationship, since they were not caused by the robot itself but by a sensor in the regrip station. Thus, figure 4.3 shows the man-machine relationship under optimal circumstances. However, using figure 4.3 one can see that the operator is theoretically freed from the robot for 84 %. According to a previously conducted work sampling, the operators' tasks were similar before the robot was installed. The operator was instructing and helping others, for example in the machine to which the robot is now connected. Hence, the robot has eliminated some heavy work tasks that previously required two operators due to heavy sheets. Furthermore, there were a lot of small batches, which required the operator to perform several changeovers as it still is. Except for the tasks that are directly linked to the robot, the operators' work have not changed in a significant way.

Technical aspects: During the interviews, it was said that some products are not automated because the operator works quicker than the robot if the batch size is low. The reason why the operator could perform the task faster is the required path of the robot. The robot must use a regrip-station in order to place products with precision in the press brake machine that a human does not need. Therefore, the cycle time will be longer per product when using the robot. However, this could be overcome by the fact that the robot may work during breaks and after working hours. It was said that at least one hour of machine time is needed to consider it to be automated since tool change and programming may be needed for both robot and machine. It was also said that even when the batch size is higher, another limitation may be the obstacle for automating the task. Such limitations could be the design of the products, affecting if the automatic press brake machine may be used at all or the ability for the robot to grip metal sheets. In the interviews, it was pointed out that the reality for a subcontractor is also that they have to adapt to the customer's demands. One of the interviewees stated that the number of orders devoted to the machine itself is also a limitation for the utilization of the robot. The served machine forms thin sheet metal within certain measures. Making it important to basically have a custom gripper to handle the size of the sheets. Otherwise, the sheet metal will wobble and the risk for collision increases. According to the interviewees at Company Sheet, the available grippers with its shortcomings delimit the number of products that can be used with the robot. The products themselves look very different which change the requirement of the gripper to look and work differently. Company Sheet consider that they have the competence to construct new grippers themselves. The price is also a major reason for making them, compared to buying new grippers.

After a software update on the movable robot, the ability to reuse different parts in the programming and change existing programs became more user friendly, stated by the operator. The different interviewees at Company Sheet stated that they believe in the technical solution that the movable robot offers. The security solution is the main advantage, the robot does not occupy the space around it with fences. Competing automated solutions are often integrated, meaning that you dedicate a robot cell with fences to a specific set of products. The manager stated that the product variety does not make it a sufficient solution for them, and integrated solutions are far more expensive. However, according to the conducted interviews, an integrated solution would possibly have been better at performing the current task, but it would also be more expensive and less flexible to change in the future.

During the observations, some errors occurred while the robot was running that made the operator interfere in order for the robot to be able to run properly again. A frequent error that made the robot stop was the sensor at the regrip station, which is the major part of "disturbances" in figure 4.2. The sensor indicated that two metal sheets had reached the regrip station, when it in fact was only one sheet. This was due to the sheets having a slightly bent profile, enough to trigger the sensor. The operator had to actively control that there was one sheet and then push a button for the robot to proceed.

Another observation that occurred a few times was that the gripper did not get hold of the sheet metal, also affecting the part of "disturbances" in figure 4.2. This could happen due to a somewhat dirty surface by impurities or grease affecting the suction cups. The result from this made the robot stop in the sequence after, but with no indication on why it stopped other than the hint of the position. One time this made the operator perform greater actions than was needed, changing pallets and restoring the position of the robot, i.e. resetting everything to zero. This could have been avoided with a recall of the previous sequence or some indication on the controller. Another time when it happened, the operator noticed why the robot stopped. Then, the operator could just pick up a sheet and provide it by hand to the robot and start again from the sequence it had stopped.

Human aspects: The manager at Company Sheet states that, people generally do not like change. Some operators may have a fear of losing their job because of investments in automation. They might not say it directly, but their actions prove it, by not wanting to change their daily duties and not having an interest in the acquired automation. For some operators, it takes longer time to accustom to the new environment. As the manager, one has to stress the fact that the goal is not redundancies but to stay competitive and, in the end, retain the jobs. Even if automated solutions are acquired there are always other tasks for the operator to do at Company Sheet. In the press brake forming department for example, there are more machines at disposal than operators.

The main operator responsible for the programming had a positive outlook on the automated solution, as stated in the interview, and hopes to use it even more. The work that the robot does is both heavy and strenuous. The operator oversees the robot while doing other tasks, refill material and change pallets to keep the robot working every now and then. Other orders have been prepared beforehand to be quite close to the robot if unexpected errors occur. Prior to the robot acquisition, the operator moved the sheet metal into the machine, waited while it was processing and unloaded the sheet, with no possibility to work at other machines.

Ergonomics: It was said during the interview that the work before the robot was perceived as boring and heavy. Now, the operator has time to do other tasks and most often it is not as monotonous and heavy as the work that the robot performs. The operators stated that the work tasks wear their backs and shoulders, every product that the robot can handle will reduce the load on the operators.

In order to analyze the operators' work tasks a RAMP analysis was carried out during the observations. The result is shown in figure 4.4. As seen in the picture, there are no immediate risks of developing MSDs. However, the tasks that are marked with grey should be investigated further, as there might be a risk of developing MSDs for the operators performing these tasks.

Results summary:	
Number of red assessments (high risk)	0
Number of grey assessments (investigate further)	16
Number of green assessments (low risk)	28

Figure 4.4. Results of RAMP-analysis from Company Sheet.

4.2 Company Metal

During the observations at Company Metal, they were experiencing some issues with the robot because of a recent update done by the robot provider. The program for the automated product had been lost and had to be reprogrammed, while some bugs were also complicating the commissioning of the robot.

Strategy: Company Metal are currently using their flexible robot at a pressing machine. They do have the ability to move the robot between machines, as they have three docking stations. However, the robot is only used at one of these machines and only for one product variant. The robot is used in a traditional way, loading and unloading the machine, while the machine performs the value-adding work. The main reasons for investing in this kind of automation were quality improvements, improving work environment and efficiency. Company Metal aims to increase the utilization of the robot to increase their own competitiveness as well as the operators' work environment. They have a strong belief in the movability of the robot, which they aim to use more in the future.

Production setting: Different operators were observed during the company visits in order to follow different types of work. The operators that were observed were all working at the pressing machines. Their work was monotonous, which included lifting material out of pallets, loading the machine and then unload to another pallet. The cycle times of the different products varied, but most had cycle times around 20 seconds. The operators were also responsible for changing tools in the machines. The first tool change that was observed lasted for 35 minutes, and the order was for 7 details, which took approximately 10 minutes. This batch was followed by a new order, which consisted of 210 products that where to go through several "steps" in the same machine. Firstly, a changeover of 20 minutes was needed before production could start. This work was repetitive with heavy lifts, bending of the body and unergonomic positions. When all products had been pressed, a tool change into a punch tool was required before the next step could start.

As mentioned earlier, Company Metal are currently using the robot for one specific product. The production setting at Company Metal resembles the schematic picture in Fig 4.1. This product is a recurring order with a volume of approximately 1000 pieces per time, which is also one of the reasons for automating the product. One batch takes about one hour, then the operator will need to change pallets and start it again. The operator might actually perform the task faster than the robot, but the robot is more consistent, leading to a small tradeoff between the two performance objectives speed and quality. During pressing, the thin sheet metal will change its form a lot. This has been found problematic in the planning stage of automating new products.

Technical aspects: One of the operators was responsible for the robot. As written before, there were problems with starting up. The operator had to make a new program for the product, which took him about 40 minutes, including robot-machine adjustments. After another 15 minutes of testing the program at low speed, full speed production could start. The program worked well until the pallet with finished goods was half-full. The robot could no longer successfully place the finished products on the pallet, instead it crashed into the products that were already there. This problem had not occurred prior to the update, hence, the operator did not have any direct solution to the problem. The rest of the day was spent on trying to get the robot to work and reprogram it, but also testing of a new solution with a conveyor belt next to the robot and machine. Because of this, no direct effects on performance objectives could be observed and a man-machine relationship could not be visualized.

Despite the low utilization, the interviewees agreed that the robot worked well with the product that has been automated. They also think that the flexibility is an advantage, one they hope to use more in the future. There are currently two operators who are able to program the robot, which they both find easy. However, the adjustments that need to be made in order to make the collaboration between robot and machine work is time consuming and not that easy, e.g. placing pallets correctly and making sure the robot goes to the correct positions. There are more products that could be automated, but the company does not have the resources that it takes to automate new products at the moment. Even though the operators could do the work faster, the product is heavy and will tire the operators over a long time. The robot offers more continuity as well as new work tasks for the operators that they seem to enjoy more according to the interviews. The company believes that the robot will prove a competitive factor, with customers relying more on the quality of a robot produced product.

For Company Metal, one of the main obstacles with automating new products are the grippers. The company produce their own grippers due to the high cost of buying new ones. Because the products look very differently, each product demands its own dedicated gripper. This means that before a product can be automated, a gripper needs to be designed and produced. According to the interviews, they have the competence to do this, but they haven't been able to allocate the required resources.

Human aspects: According to the manager, the operators have been well-informed by management that the automation is not there to take their jobs, but rather make their jobs better. They are aware of that there will always be jobs for them to do at the company. However, there were some reluctance to change work tasks, but as they got used to it, they have started to enjoy it. They are positive towards automation, even though the job could sometimes be done faster manually. However, it is mainly the younger operators that show interest in the new automation and the will to learn.

Ergonomics: The work at Company Metal is often heavy and repetitive for the operators. Furthermore, the now automated product, was seen as one of the heavier tasks before. The job included lifting approximately 10 tons per order. The operators had to rotate and witnessed of pain and discomfort. By automating products, heavy and repetitive work tasks have been eliminated, but some remain for manual labor. Due to the heavy work tasks, a RAMP-analysis was carried out to investigate the potential dangers of the work at Company Metal. The results of the RAMP-analysis are presented in figure 4.5. The result shows that the operators do not have any obvious tasks that could cause MSDs. However, some tasks might be harmful to the operators and should be investigated further and evaluated more thoroughly.

Results summary:	
Number of red assessments (high risk)	0
Number of grey assessments (investigate further)	12
Number of green assessments (low risk)	32

Figure 4.5. Results of RAMP-analysis from Company Metal.

4.3 Company Component

Company Component has been experiencing issues with the robot for a long time and still are. The robot was supposed to be in operation by the time the observations were scheduled. However, this was not the case, which is why the results of this subchapter will differ from the other cases.

Strategy: Company Component aim to automate their operations in a press brake machine. They have, unfortunately, had issues with the commissioning of the robot, to the extent that the robot is not used at the moment. In fact, the robot was only used for approximately 1000 cycles before the mentioned issues started, leading to that the robot has not yet had any effects on any performance objectives. The priority for the company has been to keep up with deliveries, due to limited time and resources the occurring problems with the robot have not been solved. Despite the issues, they believe that the solution has potential in their production and if the commissioning for this press brake operation does not work out, there are plans to install another docking station elsewhere and use the robot for loading and unloading a machine. One interviewee stated that the reasons for investing in this movable robot was to improve the work environment, quality and decrease production costs.

Production setting: The product variants are plentiful at Company Component with around 11000 individual article numbers in circulation annually. They want to automate repetitive and recurring items. The production setting at Company Component resembles the schematic picture in Fig 4.1. Some items cannot be automated because of the means of the product variation like size, graspability and reach of the robot. During the days of observation, the robot was not being used. However, due to the movability of the robot, two operators were instead able to work manually at the machine. The operators were still observed while doing their daily work. The daily operations in the press brake department vary in terms of repetitiveness and loading. The reason for this is the variation in batch sizes accompanied with the different sizes and weights of the sheet metal that is to be formed. Some tasks demand two operators, as they can be too ungainly for one operator to perform.

Technical aspects: The easy programming and movability of the robot is considered as an advantage over traditional automation, as operators without experience in robot programming can learn quickly. There are some restrictions with the functions, but with continued development and collaboration with the robot provider the programming improvements will come over time, the site manager believes. Recalling saved orders for example, gives the possibility to automate recurring orders even though the batch size might be smaller. The concept with a robot cell without fences is believed by the interviewee to be the future together with the possibility to move the automation to offer manual accessibility for the operator if needed. Fully integrated robot solutions were not considered as they were found to be much costlier and more dedicated towards a fixed article which does not offer the same flexibility, occupying space in the production system.

The grippers used are provided by the robot provider, they think that the grippers at hand are sufficient for their purpose and products. They also have the possibility to customize the gripper into three different sizes, to be more flexible and able to produce more products.

Human aspects: Generally, the operators at the site want the robot to work in order to reduce the work above shoulder height. Some skepticism is always present when introducing new equipment and ways of work, it always takes some time for the operators to accustom to the new conditions, according to the interviews. The new tasks for the operator will be to secure the material flow to the robot, to ensure that the robot is running by refilling sheet metal and change pallets with finished goods to empty pallets. The freed-up time will give the operator time to prepare upcoming orders and work in another machine next to the robot.

Ergonomics: The work environment in the press brake department is one of the reasons to use the robot. Usually, there are a lot of items that require the operator to work with the hands above shoulder height, which is a major cause for sick leave at the production site. The metal sheets vary in a span of weights up to 20 kilograms, making two operators cooperate to perform the press brake operation in those situations. In order to analyze the work tasks, a RAMP-analysis was performed. The results are shown in figure 4.6.

Results summary:	
Number of red assessments (high risk)	0
Number of grey assessments (investigate further)	15
Number of green assessments (low risk)	29

Figure 4.6. Results of RAMP-analysis from Company Component.

The tasks that generate the grey assessments are mainly the repetitive lifting of metal sheets in different shapes and weights.

5. ANALYSIS

The aim of the project was to evaluate the operational effects of movable automation as well as implications with commissioning. This chapter aims to present the analysis of the results and to provide the reader with both benefits and barriers of movable automation.

5.1 Effects of movable automation

Strategy: The site managers of the three studied companies are all positive to this new technology. One of the main reasons to invest in it has been the flexibility to move it between different machines. This motive to invest in flexible automation is in line with Miller's (2017) prediction that flexible automation could become cost-efficient in an environment with low volume and high variation production. However, none of the companies are utilizing the movability more than the ability to remove it and instead work manually in a machine, despite the fact that movability was one of the demands from the companies, identified by Löfving et al. (2018).

Production adaptation: The companies have claimed that the investment is a step towards more automation. This new technology requires the organizations to think differently than before. Existing products may need to be redesigned to fit the automation without affecting the customer requirements. In early stages of the development of a new product, graspability and design for automation can be considered to enhance the use of the robot. The product variety at the companies have been tough to overcome. Even with configurable grippers, the variation in size and batch size of the products still limits the use of the robot. Since they are all subcontractors, they will have to adapt to the customers, but adjustments for automation on appropriate products may be realized through communication with their customers. One of the managers also mentioned that more customers prefer products produced with a robot because of quality aspects. Which implies that the customers may also want to assist the implementation of products designed for automation.

Cost: Literature states that automation of manufacturing processes can decrease production costs, as productivity will rise. However, if the robot is not utilized, it is not possible to make it cost-efficient. During observations at Company Sheet, the responsible operator was actually free from the robot about 84 % of the time, while the robot could work without any disturbances. This means that one operator at Company Sheet can, theoretically, produce twice as much for 84 % of the working hours. Due to the problems the other two companies were experiencing, the observations could not be done in the same way but based on the interviews, an operator could be freed from the robot for a substantial part of the working day. Thus, robot and operator could work independently of each other, increasing productivity and the ability to deliver on time, especially of the products that previously demanded two operators. Moreover, the ability to deliver has been identified as one of the most crucial competitive factors by the companies, but also as one of the main reasons more products have not been automated. The explanation to this is that they need to deliver on time to their customers, leaving no time to program the robot and develop new tools.

Quality: The companies stated that the work environment and quality aspects were major reasons for investing in movable robots. Robots are better than humans when it comes to repeatability and accuracy according to Bossen and Ingemansson (2016), which is why automating larger product series should increase quality. Company Metal stated that this was one of their main selling points, which is appreciated by their customers. By utilizing the robot better, these companies could probably increase the quality of their products, especially when it comes to the recurring, large series products.

Speed: According to the conducted interviews, an operator often works faster than the robot. They also underline that the robot can work during breaks and for some time after working hours, which may be enough to even out the speed difference. Perhaps the time could also be regained when the robot and operator work simultaneously. Moreover, the robot is not meant to replace the operator in the factory, but rather relieve the operator from heavy work, to let the operator perform the less heavy tasks. Since the operator is working beside the robot with another task, the speed is not that important for larger product series. However, automating smaller product series is not plausible due to several factors. The time spent on programming takes longer time than finishing the order manually, especially if the order is not recurring and only comes occasionally. Despite the easy programming, the product series need to be of a certain size in order to motivate automation, otherwise the changeover time will be too long. Therefore, spending time on automating new products that are recurring and of a relatively large series, while having the operators work with the smaller series, could increase competitiveness and productivity of the studied companies.

5.2 Human perspective on automation

Subcontractors always strive to offer their customers a competitive product, both regarding price and quality. To do that in the long run on the global market, investments in new technology is needed. The global trend towards mass customization changes the ways of manufacturing worldwide, which require all manufacturing companies to be more flexible, to manufacture small batch sizes and small volumes with many variants (Mattsson et al, 2014). An investment in flexible automation will affect the operators' tasks and bring a new set of assignments in the daily activities. New technology requires new knowledge from the operators, such as programming skills and monitoring skills for example (Regeringskansliet, 2016).

Despite the low utilization, the three companies have all been positive towards the potential of the automated solution. Although, it is used very scarcely, and the resources have not been allocated accordingly to make the robot more occupied. According to the managers and operators the machine utilization during recent years have been crammed due to the economy boom. One factor that affects the use of automation, called cognitive overhead (Parasuraman & Riley, 1997), corresponds to the workload of the operator. From the different cases studied in this thesis, the decision to use the robot is only handled by a few people, mainly the production manager together with the operator with most experience. One of the reasons for the low utilization of the robot may be the weekly demand to deliver products, restricting the time to set aside to introduce more products for the robot. Another reason may be the fact that it is no rush to make the robot work, since it is just an aid for the existing production, meaning that the company can produce their products regardless of the robot's involvement. The production can proceed even if the robot is unused, which is a part of the robot's flexibility but can also be the reason for its vacancy.

All companies in this study are subcontractors processing metal components according to their customers' demands. The operators are used to do this manually with a machine at their disposal, in these cases, either press brake forming or drawing operations are considered. These work tasks require the operator to have a degree of craftsmanship in metal deformation. The benefits for automating products for the operators are mainly a reduction of the physical workload experienced by the operators. Although, when adding the aid of a robot in the system, new obstacles needs to be considered. One of the main reasons for acquiring automation is to reduce the mental workload (Parasuraman & Riley, 1997). However, introducing new work tasks, such as robot programming, to these operators who have been dependent on their craftsmanship in their work, may instead lead to a higher mental workload which may affect the usage of the automation.

5.3 Production ergonomics

All companies declared that improving work environment was one of the main reasons for investing in the flexible automation. The products that are automated at the three companies have been identified as heavy, repetitive and potentially dangerous to the operators. All three factors that influence the development of MSDs, declared by Berlin and Adams (2017), were present. The operators had to work with bad postures, high forces and either often or for a long time. Company Sheet and Metal were the companies that had the robot working with their products. Operators at both these sites expressed that they enjoyed their work more now that the robot is there. Their work has more variety and heavy work tasks have been removed. There are still some heavy lifting and repetitiveness, but there will be natural breaks when pallets need to be changed or programming of the robot needs to be done. At Company Component the robot has not worked as intended. The robot has not been able to perform the press brake operations correctly. This is problematic as press brake forming consists of work tasks that the operators need to do above their own shoulders, while the sheets are also heavy. However, there have been three products automated before the software problems occurred. If they could start robot production again, much unergonomic work would be eliminated.

The RAMP-analyses show that none of the companies have any work tasks consisting of obvious ergonomic risks. However, there are tasks that should be investigated further, which could be potential products for automation. Since the operators have witnessed about pain and discomfort, perhaps some of these grey results of the analysis should be automated, given that the series are of a certain size. By having the operators produce the small batch products and the robot produce the larger batches, it is believed that the work environment would increase substantially. The operators would have more variation in their work, with different products, more changeovers and also the sporadic interactions with the robot.

5.4 Benefits and barriers of movable automation

To conclude the analysis two lists of bullet points are presented to visualize the potential benefits and barriers of movable automation:

Benefits:

- Flexibility of utilizing one robot together with several machines
- Cost-efficiency of having one operator serving both the robot and a machine
- The continuity of a robot can increase quality of both processes and products
- The robot can work during breaks and after working hours
- Potentially improving work environment for operators

Barriers:

- Lack of resources at SMEs in the form of competence and time
- Too high product variety and too small batch sizes
- The grippers are not designed to handle product variety
- Products are not adjusted for automation

6. DISCUSSION

This chapter discusses the choice of methodology and how the results and analysis have been affected by it.

6.1 Methodology

The mixed methods approach was chosen in order to achieve triangulation and thus more reliable results and a broader perspective. However, the methodology could not be used consistently at the three companies, due to the fact that all case companies were using the flexible automation differently if it was used at all. The activity list used during observations was not deemed useful at Company Metal and Company Component, since the idea was to observe the man-machine relationship between operator and the flexible automation. Because the robot was not used, there was no relationship to observe. Instead, only the manual work was observed and used for RAMP-analysis. RAMP was chosen as ergonomic evaluation tool during a project meeting, as it deals with typical work tasks that were performed at the evaluated companies.

The interviews emanated from the same script with small adjustments to fit each individual company better. These could be done without any implications and the results from the interviews were aligned with the results from observations, which leads to the belief that the results are reliable. Furthermore, the literature study that is presented in the theory chapter is deemed sufficient to answer the research questions of this thesis, as several references have been used to strengthen the results.

6.2 Results & analysis

The observed cases in this study have been SMEs with limited experience with state-of-the-art technology. The technology, in this case, is flexible automation in an early phase of the development, making the companies early adopters of the technology. The lack of experience has been demonstrated in different ways, necessary adaptations have been discovered after installation within production layout, product design and robot grippers. Adaptation to automation for the companies have taken longer than expected. Resources for adapting product design and other processes have lagged behind in many respects, which has led to that the automation solution has been put aside for now.

The aim of the thesis was initially to evaluate the operational effects of movable robots on SMEs. However, this has only been possible at one of the visited companies, which led to a change of the aim into also analyzing the difficulties with utilizing flexible automation. It was intended to use the methodology the same way throughout the project, but as stated in 6.1 this was not possible. Thus, the results between the companies differ, but they are still useful. Because of the nature of the results, the analysis of the effects of flexible automation are mainly based on observations and interviews.

However, the results and drawn conclusion are believed to have sufficient validity, as several interviews have been conducted and proofread by representatives of the three different companies. Moreover, the different companies and their work has been observed, thus, a broad understanding of these enterprises has been acquired. The potential and barriers of movable automation were similar at the three companies, which leads to the belief that the results are reliable, as the studied companies are all in the same line of business.

7. CONCLUSION

The direct operational effects of the flexible robot for a low volume with high product mix production cannot be established at this point. The effects regarding performance objectives such as cost, speed and quality can only be evaluated through limited usage data at the companies. The results have shown that the operators witness of a better work environment while the robot is working alongside them. Therefore, increasing utilization of the robot is in both the operators' and companies' interests, as this might lead to fewer sick leaves and allow the companies to keep their competent employees. Moreover, by producing more products with the robot it is likely to increase quality, productivity and contribute to a more sustainable workplace, thus the competitiveness will increase. Therefore, allocating more resources to the development of robot production at the three companies is recommended. However, at the same time there has been a boom in economy during which machine utilization has been high and actively working to bring in new products has not been prioritized. They have put their resources on delivering existing products in time to customers. The studied companies have all been subcontractors where there is an uncertainty to keep products in production. To work on automating a product that you do not know reoccurs is not sustainable. Furthermore, shortcomings in the functionality have been revealed through usage in industry, which have led to gradual improvements in the technology. Perhaps the utilization of a flexible robot would be higher in a more predictable environment, with a lower product mix and higher volumes. However, with the adjustments made in the technology and the increased understanding at the companies, they all have a positive outlook that the automation has the possibility to be successful at a low volume, high mix production.

Conclusively, the potential of movable automation is believed to become a competitive factor for the companies that choose to invest in it. However, there are barriers that these companies need to overcome in order to use the technology efficiently and gain advantage of the positive effects. By having a close collaboration between industry and the robot provider, these barriers could possibly be overcome. The benefits and barriers are presented once again.

Benefits:

- Flexibility of utilizing one robot together with several machines
- Cost-efficiency of having one operator serving both the robot and a machine
- The continuity of a robot can increase quality of both processes and products
- The robot can work during breaks and after working hours
- Potentially improving work environment for operators

Barriers:

- Lack of resources at SMEs in the form of competence and time
- Too high product variety and too small batch sizes
- The grippers are not designed to handle product variety
- Products are not adjusted for automation

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9. APPENDICES

Appendix A: General interview template

General
Tell us about yourself and your role at the company.

How did you get into this business?

Robot Utilization:
Is the robot always used when possible?

How is it decided when the robot should be used?

Are products not automated due to fact that they are faster to produce manually?

What's your thoughts about the time it takes for changeovers to robot production?

How do you experience the tasks that you do instead, when the robot is used?

Do they differ much?

Do you always have tasks to do when the robot is used?

What's the decision basis for automating new products?

Programming and fear of automation:
Do you have any experience of programming the robot?

What do you think of the programming?

How have your work tasks changed since the robot acquisition?

How do you experience the workload compared to before the robot was acquired?

What are your general thoughts of the robot?

What do you think of the potential of the robot, here at your company?

Do you see any limitations with the technology?

Has the robot turned out a profitable investment for you, or when will it be?

How big do the batches need to be in order to motivate automating a product?

Do you think your work tasks may become more enjoyable if the movability is successfully utilized and the robot does the heavy, repetitive tasks instead of you?

How do you think your role here at the company will change if the flexibility is better utilized?

Grippers:

Tell us about the grippers you're currently using.

What are your demands on the grippers?

Are they available on the market or do you make your own?

Appendix B: RAMP

RAMP I - Checklist for screening physical risks for manual handling			
Note! Write an "x" (small x) in each " Yes" or "No" statement box under each question.	**Yes**	**No**	**Comment:**
1. Postures			Write your comments, if any, in the white fields below:
1.1 Does work occur often or for a long time* in any of the following unfavourable postures? ** often = about 100 times per work day or more* ** a long time = about 30 minutes per work day or more*			
head bent backwards			
back/upper body bent or twisted - forwards, backwards or towards the side			
arm almost or fully stretched forwards (the hand more than about 45 cm from the spine)			
hand above shoulder height or below knee height			
hand/arm brought outwards to the side (to the right or to the left)			
1.2 Does work occur in any of the following unfavourable postures about 1 hour per work day or more?			
head clearly twisted or bent - forwards or towards a side			
hand clearly bent upwards, downwards or towards a side			
legs or feet have insufficient space, or the surface is unstable or with a slope			
2. Work movements and repetitive work	**Yes**	**No**	
2.1 Does work occur in any of the following ways?			
the work cycle is shorter than 30 seconds			
the work cycle is between 30 seconds and 5 minutes			
similar work movements are repeated more than 1/10 up to half of the work cycle time			
similar work movements are repeated more than half of the work cycle time			
If "No" on all in 2.1, go to 3. If "Yes" on any in 2.1, answer 2.2 below.			
2.2 How long time of the working day does such work occur? Choose one alternative.			
the work or similar work tasks are carried out between 1 and 4 hours of the work day			
the work or similar work tasks are carried out for more than 4 hours of the work day			

3. Lifting work	Yes	No	
3.1 Does lifting of loads occur? If "No", go to 4.			
3.2 How heavy are the loads and how often are they lifted?			
less than 3 kg			
- more than 100 times per work day			
3-7 kg			
- more than 40 times per work day			
more than 7 kg - 14 kg			
- more than 20 times per work day			
more than 14 kg - 25 kg			
- more than 5 times per work day			
more than 25 kg			
3.3 Do the lifts generally occur in any of the following unfavourable postures?			
back/upper body clearly bent			
back/upper body clearly twisted			
hand above shoulder height			
hand below knee height			
hand outside forearm distance			
arm clearly brought outward (to the right or to the left)			
lifting/holding with overhand grip (palm facing downward)			
one-hand lift where the load exceeds 6 kg			
lifting while seated where the load exceeds 7 kg			

4. Pushing and pulling work	Yes	No	
4.1 Does pushing and pulling work occur? If "No", go to 5.			
4.2 How large is the exerted force in the pushing or pulling work?			
the starting force (the force to start the object moving) exceeds 150 Newton			
the starting force (the force to start the object moving) exceeds 300 Newton			
the continuous force (the force to keep the object moving) exceeds 100 Newton			
the continuous force (the force to keep the object moving) exceeds 200 Newton			
4.3 Does the pushing and pulling work generally occur in any of the following unfavourable conditions?			
the gripping height clearly deviates from elbow height			
the work is carried out with the back/upper body clearly twisted			
the force is exerted towards the side or upwards (i.e. not straight forwards or backwards)			
the force is exerted with one hand			
the pushing or pulling is carried out often (approx. more than 100 times per work day)			
the pushing or pulling distance exceeds 30 meters			
4.4 Are load carriers with 1-2 wheels (e.g. two-wheel cart) or similar used, under the following condition?			
the employee bares the whole or part of the load, and the load weight exceeds 100 kg			

5. Influencing factors	Yes	No	
5.1 Influencing physical factors hand/arm - do the following occur? The times refer to "per work day".			
the employee is exposed to hand-arm vibrations more than 20 minutes (10 for strongly vib)			
the employee is exposed to hand-arm vibrations more than 90 minutes (60 for strongly vib)			
warm or cold objects are handled manually			
the hand is used as an impact tool often or a long time*			
holding hand tools weighing more than 2.3 kg for more than 30 minutes			
holding precision tools weighing more than 0.4 kg for more than 30 minutes			
5.2 Other physical factors - do the following occur? The times refer to "per work day".			
the employee is exposed to whole-body vibrations more than 1 hour			
the employee is exposed to whole-body vibrations more than 6 hours			
the visual conditions are insufficient for the task			
the work is carried out in hot or cold temperatures or in draughty environments			
standing or walking on a hard surface more than half of the work day			
prolonged sedentary work without possibility to change to do the work standing up			
prolonged standing work without possibility to change to do the work sitting down			
kneeling/squatting more than 30 times or more than 30 minutes			
5.3 Work organisational and psychosocial factors - do the following occur?			
there is no possibility to influence at what pace the work is performed			
there is no possibility to influence the work setting or how the work shall be carried out			
it is often difficult to keep up with the work tasks			
the employees often work rapidly in order to be able to take a longer break			
there is no possibility for recovery time during the work (other than formal breaks)			

6. Reports on physically strenuous work	Yes	No	
6.1 Do documented reports exist on physically strenuous tasks (near misses, incident reports, journal notes, or other) when carrying out the work task?			
6.2 If "Yes" on 6.1 , what type of work that has led to this? If "No", go to 7.			
lifting			
holding/carrying			
pushing/pulling			
pushing with hand or fingers			
other: (if any, please replace this text)			

7. Perceived physical discomfort. Ask five people who perform this work task	Yes	No	
7.1 Are there parts of the work which lead to physical discomfort (e.g. in muscles or joints) during the work day? Answer "Yes" if any employee experiences such discomfort.			
7.2 If "Yes" on question 7.1, which is the worst task?			
Person 1			
Person 2			
Person 3			
Person 4			
Person 5			

Other comments (if any, please write below)