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An Investigation into Barriers for Flexible Automation in SMEs

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

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Abstract

The market is moving towards a higher degree of customisation, which forces companies to become more flexible in their production. As the level of automation is increasing in industry the concept of flexible automation is becoming more relevant but there are problems with implementation in SMEs. The study therefore aims at determining what these problems are and suggest recommendations for how to mitigate the effect of the problems.The study was done by conducting interviews with experts working in flexible automation and companies which are implementing the concept as well as a literature review. The result is a number of identified problems. These include abstract issues such as the difficulties of a mass customisation market putting demand on SMEs, lack of competence when it comes to investment and operation and poor awareness and formalisation of own production system, i.e. production engineering. Further, technical issues such as lack of scalability, lack of flexible tools, lack of flexible programming and difficulty integrating automation technology with surrounding system were included. Recommendations are given to mitigate some of these problems; try to gain competence by transforming to a learning organisation and by reducing changeover time with changeover reduction methodology. If the problems are not resolved, SMEs will have a hard time keeping up with the customers' need and might loose to offshore outsourcing in countries with cheaper labour.

Keywords: Flexible Automation, SME, Problems, Barriers.

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Table of Contents

Contents

1 Introduction

This chapter introduces the background of the thesis, the larger context, the aim and limitations of the thesis as well as the specification of the issue.

1.1 Background

Small and medium sized enterprises (SMEs) are widely considered an integral part of the growth of an economy. This is very much true in Europe where SMEs accounted for 60% of growth in added value between 2016 and 2018 [1]. However recently much of this growth comes from increased growth in micro enterprises whereas the importance of medium sized enterprises is in decline. European SMEs exhibit high growth in industries with low knowledge demands, leaving high knowledge sectors behind .

These two facts do not shine an optimistic light on the implementation of cutting edge automation technology in manufacturing SMEs. At the same time automation and digitisation is an important factor in the competitiveness of SMEs [2], especially in a high wage climate such as Europe. This can be seen in the EUR 920 million the European regional development fund spent on digitisation projects in SMEs spent to date .

To realise visions of increased competitiveness however industry robots must become acclimatised to the production environment often present in manufacturing SMEs [3], particularly subcontractors: low volume, high variation production. However, there are still issues to overcome in this transition.

1.2 Larger context

This section will introduce the previous thesis that led to this continuation, the larger research project this thesis is part of and that project's mother project.

1.2.1 Previous Thesis

This thesis is a continuation of a previous master thesis [4]. Their project aimed to evaluate the performance of a movable robot at a few case companies and investigate how the work environment have changed. This thesis will involve the same three case companies but will focus more on what problems they have. The perspective of the new thesis will also be wider as it aims to gain a more general estimation of problems in flexible automation for SMEs.

1.2.2 LoHi

Similarly with its predecessor this thesis is done within the framework of the LoHi Swedprod project. The project aims to analyse the needs and opportunities for cost efficient and flexible automation for a low volume (Lo) and high mix production (Hi). The case companies and their flexible automation supplier are also part of this project [5]. The project has released an automation guide which will be compared to the results in the recommendations chapter.

1.2.3 Production 2030

LoHi is part of a larger research project called Production 2030 [6]. It is a strategic innovation programme supported by Vinnova, the Swedish Energy Agency and Formas. The project's aim is to make Sweden leading in sustainable manufacturing by combining different sectors making academic production knowledge applicable for commercial production.

1.3 Aim

The project aim is to identify problems within the use of flexible automation in SMEs as a basis for future research and an indicator to industry. Problems will be identified from multiple perspectives including but not limited to investment, operations and company strategy. Furthermore recommended actions will be suggested to help mitigate the effect of some problems.

1.4 Limitations

The project has limitation with regards to data collection, project time and project resources. The case company data will be collected from a limited number of companies who all use the same brand of flexible automation platform, and a few experts, which might reduce the general applicability of the results. The project is limited in time with the project stretching roughly 20 weeks and the group size of two. The resources of the project allow case studies but no own testing.

Due to the impossibility of company visits as a result of the Corona-virus the project has had to change focus from investigating the use and problems of the case companies' flexible automation solutions to a more general investigation into the problems with flexible automation in SMEs. The change in aim was made in the middle of the project which has limited the time spent on the current aim. However some early data and results were deemed transferable to the new aim.

1.5 Specification of issue under investigation

With the help of the problem description presented in the aim section the following research questions have been formulated:

- What problems are there with flexible automation in SMEs?
- What problems are most significant?
- What solutions, tools and methods could be used to mitigate the significant problems?

2 Theory

This chapter introduces some of the central concepts of this thesis. This entails defining and describing the characteristics of those concepts. The concepts include SMEs as compared to larger companies, flexible manufacturing, changeover, batch size and learning organisation.

2.1 SMEs: Characteristics compared to a larger company

The European Commission defines SMEs [7] as enterprises with fewer than 250 people, an annual turnover of less than EUR 50 million and/or a balance sheet not exceeding EUR 43 million.

The fact that SMEs differ from their larger counterpart is well cemented in literature. Management in SMEs is often centralised and the organisational structure very flat [8][9]. This reduces the bureaucracy layers in the vertical direction and makes managers highly visible. The drawback of this is that managers in SMEs often spend their time "fire fighting" instead of managing the long term strategy of the company. It also makes it more likely that the manager is well versed in core business operations but lacking in competence when it comes to formal management skills [9]. The central role of the manager also results in a more unified corporate culture. This however comes with the drawback of being highly vulnerable to bad management.

The flatness of the organisational structure enables shorter and more direct communication lines making changes easier. With fewer layers comes fewer specialised employees resulting in a trend of SME employees often filling multiple roles. This can result in a lack of in-depth competence [9]. For instance SMEs often have no dedicated IT department [8]. Improvement and education initiatives might be hampered by the general lack of specialised, educated employees and formal systems [9].

Manufacturing systems in SMEs often have low levels of system integration and low levels of automation [10]. Most work is thus done manually and suffer from efficiency problems [3]. The lack of formalised systems makes the storage of written company competence less likely to happen [9].

Employees in SMEs often harbour resistance to new technology [10]. The contrary is argued by Hansen, Bilberg, and Madsen [11] who claims that SMEs are prime candidates for new technology.

Wadhwa points to one main difference being that SMEs often face a much more uncertain external climate [12]. Manufacturing SMEs in contract manufacturing often work with frequent product changes and a wide range of products and variants [8].

2.2 Flexible manufacturing

Flexibility can be broken down into multiple parts, where process and product flexibility are the two parts most central to this thesis. Process flexibility means the ability to produce large volumes of a set of products with minimised changeover losses between them while product flexibility means the ability to efficiently introduce new products into the production system.

2.2.1 Flexible Automation

Flexible automation is defined by the Encyclopedia of Production and Manufacturing Management [13] as a type of manufacturing automation that exhibits flexibility, primarily in the form of ability to produce different parts and variants.

For the purpose of this thesis, flexible automation is defined as automation which has been adapted to work in a low volume high variety production setting which requires very high flexibility. This is to the contrary of traditional automation that is made for high volume low variety production, which generally requires less flexibility. There is however not a quantified limit as to when it is traditional automation and when it is flexible automation.

Advances in flexible automation include areas such as [3] collaborative robots meant to work alongside a human operator, autonomous automation solutions capable of both moving material and themselves autonomously and mobile automation which adds mobility to a traditional industrial robot.

Autonomous automation solutions segment has yet to impact manufacturing in a major way and is now more common in research than industry [14]. In 2015 the technology was able to, in a controlled environment, solve tasks in industry such as continuous part feeding, simple assembly operations and some continuous quality and process control [15]. The technology has however started to move away from only being a part of academia to more commercial sectors which is evident from several of the largest robot manufacturers including ABB, KUKA and Yaskawa selling or developing their own lines of mobile robots [16][17][18].

2.2.2 Flexible tooling

Bélanger-Barrette [19] from Robotiq are of the opinion that flexible grippers hold advantages such as reduced setup time, freeing up of floor space from elimination of tooling stations and reduced robot head weight when compared to traditional tool changes in a low volume, high mix environment. Another robotiq member [20] presents the opinion that situations suitable for flexible grippers include product mixes with different dimensions but similar geometry, products with asymmetrical geometry and fragile products.

Research has moved far within the realm of grippers with hand like structures with high dexterity and flexibility [21]. However, Bouchard [22] indicate a trade off between performance, cost and flexibility, where speed, precision, repeatability and cost efficiency is often traded for higher flexibility.

2.3 Changeover

Changeover is defined as "the total process of converting a machine, line, or process from running one product to another" by Henry[23].Lowering changeover time is central to increasing process flexibility. Changeover will include everything from preparing the machines, supplying the material to clean-up and documentation. Changeover consist of 3 major components sometimes referred to as the three ups [23]:

- Cleanup, which is the process of getting rid of any material from the previously run batch. This commonly means getting rid of parts, material and general tidying. In some cases it can also mean sterilisation of machines and deep cleaning.
- Setup, which is the process of preparing for the machine for running the new product. In many cases this will mean changing tools, machine adjustment but also tasks away from the machine such as documentation, material handling and quality inspection.
- Startup, which is the time from when the other changeover tasks has been completed until normal production is achieved. It is common in the startup phase that jams occur or production need to be stopped to make adjustments.

Lowering the changeover time will thus increase the process flexibility.

Product variety has also increased significantly in the last 30 years [23]. Take the example of Coca-Cola, there was one flavour 50 years ago but today there are at least 150 different variants, with differences in flavor, size and container type. This increases the needs for efficient changeover leading to the bottling plants sometimes performing several changeovers per shift. This trend can be seen in almost all industries as the concept of one size fits all becomes less interesting to consumers [23]. This forces the factories to increase process flexibility in order to produce lower volumes of items without losing efficiency. Low changeover time can be considered essential for successfully implementing a low volume high variety production system[24].

Long changeover times were, until the advent of SMED (single minute exchange of die) and similar ideas, regarded as a unchangeable standard where it could take several hours to change between different product types [25]. To counter this large batch sizes were used to reduce the number of necessary changeovers. In Japan at Toyota where resources and space were generally far more limited a larger focus were put on reducing the changeover times in order to be more able to produce products in a desired sequence rather than being limited to focusing on one product for a longer period and then changing to the next. Between 1945 and 1971 Toyota managed to reduce some setups that were 3 hours down to 3 minutes.

Setup reduction has been a very important topic for Toyota in japan [25] as low setup is a vital part of being able to achieve just in time (JIT) which requires the ability to quickly change between batches to keep inventory levels low. SMED is a methodology developed by Shigeo Shingo at Toyota [23], it is used to reduce changeover time in production. A version of SMED developed by Henry [23] is used for achieving lean changeover, it is called ESEE which means Eliminate, Simplify, Externalize, Execute.

Eliminate
The first step is the most important one as there are generally unnecessary operations. Often operations that once served a purpose are still being done just because they always have, regardless of value. Secondly it is important to do this step first as it would be a waste of resources to go through steps on simplify etc on an operation which is going to be removed [23]. The process works by eliminating moments where waste can occur, one example could be where parameters of two products are unnecessarily different creating changeover which could be avoided. It can also be the elimination of documentation which is no longer necessary even though it might have been at some point. The step could be summarised as removing anything which is not necessary essentially focusing on the value adding work.

Simplify
There is almost always an easier and simpler way of performing a task [23]. By making operations simpler and easier, time will often be saved, making the process faster. Henry [23] generally recommends that the improvements come from the people working closest to the problem, making it an important task to release the employees imagination in order to determine how to improve their environment.

Externalise
Is the same as in SMED where the tasks are separated into internal and external tasks. Internal tasks need the machine to stop in order to be done, while the external tasks can be done while the machine is running [23]. Externalisation is not likely to decrease the labour time but in many cases the cost of downtime will far outweigh the cost of extra labour and new tools, which will help the externalisation.

Execute
In the execution phase the aim is to create an efficient ramp-up as there will generally take some time after the changeover until the production is at full speed [23]. Much of the ramp-up is caused by variability which makes the process unable to be exactly the same every time. This variability will in many cases be due to the material not being exactly the same, which will require adjustments.

Reducing the changeover of one piece of equipment will not create a significant benefit to the production [26]. The changeover will not become effective until the reduction is expanded sideways creating reductions in all parts of the products route and for all products, achieving this is called achieving single setup. Once this has been done the lot size should be recalculated as the reduction in setup will allow for more smaller batches to be produced without loosing capacity.

2.4 Batch size

As process flexibility is about efficiently being able to produce smaller volumes per production run, a very relevant factor is the batch size. For the purposes of this thesis, batch size (or lot size) is defined as "the quantity of an item manufactured in a single production run" [27] i.e. without needing changeover or other changes in machines. Finding the right batch size increases performance in a system where flexibility is required [28]. This is due to the fact that there is often a changeover time in between batches and thus a larger batch divides that changeover time over more products. Inversely having a too large batch size means flexible planning becomes harder. Thus, determining batch-size is becoming increasingly important as more companies are increasing their product variety [29].

Academics have been producing different models, systems and algorithms to mimic a real case ever since economical order quantity (EOQ) was established. This has led to a wide array of models[30]. The methods covered in detail below are EOQ, statistical inventory models and dynamic lot-sizing. Lot sizing problems with capacity constraint are generally NP-hard which means finding an optimal solution will require a rapidly increasing amount of computational power as more complex situations are analysed [31]. Thus, many solutions rely on heuristics or algorithms that approximate a good enough answer as opposed to the optimal answer [30].

2.4.1 Wilsons formula (EOQ)

One of the most common aspects for determining the optimal batch-size is cost [25], where the cost of making an order is balanced against the cost of carrying inventory in order to determine economical order quantity (EOQ). This method rests on six assumptions [25] :

- Zero production time
- Instant delivery
- Precisely known demand
- Even demand
- Known and even setup time
- Single product or no shared resources

These constraints results in the following equation and solution for the optimum order quantity Q* respectively with the variables explained below [25]:

$$Y(Q) = \frac{hQ}{2} + \frac{AD}{Q} + cD \tag{2.1}$$

$$Q* = \sqrt{\frac{2AD}{h}} \tag{2.2}$$

The order cost A [currency] will be the cost of making the order, Schmidt, Münzberg, and Nyhuis [29] list these items which goes into determining the the cost of orders:

- Material and wage costs for cleaning a system
- Wage costs for adjusting and mounting special equipment
- Tool change and transportation costs
- Administrative costs for generating production orders

- Ramp-up costs at the start of production e.g., due to more rejects
- Hourly rates for machines for the setup time

They also list the components of the inventory carrying cost h [currency/pcs]:

- Interest on tied-up capital
- Depreciation, insurance, maintenance etc. costs for buildings and storage systems
- Administrative and maintenance costs for stored articles
- Risk related costs e.g., due to decreasing value
- Costs for depositing and removing products from storage

Further, the equation uses production cost c [currency/pcs], which does not include setup cost [25]. D [pcs/time] is the demand of the product and Q [pcs] is the lot size while $Q*$ [pcs] is the optimum lot size.

The above mentioned assumptions are very unrealistic to achieve in any environment but the EOQ is still a common method for batch size calculation. But, even though EOQ is commonly used there are many implication of the chosen lot size which EOQ isn't able to account for [29]. Example of implications from lot size can be work in progress throughput time and delivery reliability. Further the optimum EOQ might not be correlated with the optimum batch size from a production technical perspectives such as limited capacity, other dependent products and varying setup times. This leads Hopp Wall and Spearman Mark [25] to recommending limiting usage of EOQ and similar functions to buy decisions and not production scheduling [25].

Another lesson that should be learned from Wilsons EOQ formula is the fact that deviation from the optimum lot size has a relatively small impact on the total cost [25]. For instance using a lot size double or half the size of the optimal only results in a 25% increased cost. Thus too much effort towards finding the optimum lot size might be a lot of work relative to the impact it has.

With the limitations described above, the main takeaway is that while EOQ is very easy to use if the relevant data is available and personnel with the right competency is present it is often not a perfect representation of reality and thus should not be the basis for batch size in a too complex system. It would be perfectly acceptable to use when capacity is not an issue for the specific product or other resource sharing products and the demand is known and level.

One significant variation of the EOQ formula is the economic production lot (EPL) model which modifies the EOQ by adding a fixed but non-zero production time for each product thus limiting the assumption of infinite capacity of EOQ. The solution is a similar expression to EOQ [25]. This extension could be under the same conditions as EOQ but also when capacity is limited.

2.4.2 Dynamic lot-sizing

One expansion of the EOQ formula that seeks to remedy the idealistic assumption of constant demand is the dynamic lot sizing solution. It begins by dividing the desired planning horizon into discrete periods of suitable length. One can then assign different demands to different periods [25]. The equation is the same as the EOQ with the difference being an added variable for inventory from previous period I_t and that variables is vectorised such that for the demand variable D:

$$D \rightarrow D_t \tag{2.3}$$

where $t = 1, ..., T$ are periods from start to the end of the planning horizon T.

This equation is often solved by computer and one prominent heuristic algorithm to solve this is called the Wagner-Whitin procedure [25]. The Wagner-Whitin procedure begins by looking at the production possibilities of the first period and determining how many products should be produced in that period. The answer is of course trivial and says the demand for period 1 should be produced in period 1, otherwise the demand will not be met. The next step is to expand the time horizon until period 2. One must then decide if the demand of period 2 should be produced in period 1 or in period 2. Producing only in period 1 infers a holding cost of the demand of period 2 being warehoused between period 1 and 2 while producing the demand of period 2 in period 2 infers an extra setup cost in period 2 and thus minimising these two is used as basis for the decision. The horizon is then expanded further to include period 3. The production to fill the demand of period 3 is then either placed in period 1, 2 or 3 based on the same minimisation as before. The horizon is then extended and the process repeated until the schedule for the whole planning horizon is completed. The solution here is thus given as the periods and amount in which one should produce.

Despite the alluring aspect of being able to handle whatever demand variation occur, this method has one glaring weakness: it assumes that the demand variation of the system is known for at least some planning horizon ahead [25]. When talking about these kinds of predictions with regards to demand one soon enters another field, namely forecasting. Further, the dynamic lot sizing model retains most of the assumptions of the EOQ and therefore shares most of its weaknesses [25]. One situation where this method could be used with great success is as a basis for a purchasing situation where the demand is known for time period, e.g. because of a lock-in system of orders.

2.4.3 Statistical inventory models

One way the inherent variation and uncertainty of demand over time can be handled is by designing a model which takes into consideration the statistical distribution of the demand [25]. One such model is called the (Q, r) model and describes a situation where a warehouse is to be kept at a minimum safety stock level when demand is received one piece at a time and irregularly. The model thus relies on the follow five assumptions:

- Known and fixed replenishment delivery times
- Unfilled demand is delivered by back order
- There are no batch orders
- There is a fixed cost associated with or a maximum number per time period of replenishment.
- Single product or no shared resources

The Q and the r in the name of the model stand for the order quantity and the inventory level which triggers an order respectively. The time before that order is delivered, L is therefore the window of time where a stock out, i.e. the inventory level reaching 0, can occur. The point of the (Q, r) method is to ensure that the risk of this happening is at an acceptable level as a stock out is associated with certain costs [25], often per unit that is sold as back order. The following variables are introduced to formulate the model:

- D = demand per time unit, often year [pcs]
- L = replenishment lead time [time unit]
- X = demand during replenishment lead time, random variable [pcs]
- $\Omega = E(x) = D * l$ = expected demand during replenishment lead time [pcs]
- Σ = standard deviation of demand during replenishment lead time [pcs]
- $p(x) = P(X = x)$ = probability demand during replenishment lead time equals x
- $G(x) = P(X \leq x) = \sum_{i=0}^{x} p(i)$ = the likelihood that demand during lead time replenishment is less than or equal to x, (cumulative distribution function)
- A = fixed cost per replenishment [currency]
- c = unit production cost [currency per [pcs]
- h = unit holding cost, often per time, often year [currency/pcs*time]
- b = cost per backorder unit per time, often year [currency/pcs*time]
- $s = r - \Omega$ = safety stock [pcs]
- $F(Q, r)$ = order frequency, often per year [orders/time]
- $S(Q, r)$ = fill rate
- $B(Q, r)$ = mean number of backorders
- $I(Q, r)$ = average inventory level

To be able to create an analytically solvable total cost equation, the mean number of backorders $B(Q, r)$ is approximated as $B(r)$ [25]. The equation is then given as :

$$Y(Q, r) = \frac{D}{Q} * A + b * B(r) + h * (\frac{Q + 1}{2} + r - \Omega + B(r)) \tag{2.4}$$

and thus for finding the optimal value of r and Q, given as $r*$ and $Q*$ respectively, is done as 2.5 and 2.7 respectively:

$$r* = \Omega + z * Sigma \tag{2.5}$$

Where z is given as the z in the standard normal table such that:

$$\Phi(z) = b/(b + h) \tag{2.6}$$

$$Q* = \sqrt{\frac{2AD}{h}} \tag{2.7}$$

The observant reader will see that the expression for $Q*$ is the same as $Q*$ in EOQ.

2.4.4 Capacity based

In Toyota production system and similar systems, minimal batch size is always preferred [23] as it allows for less work in progress, less inventory cost and a higher customer service level due to the increased flexibility. One method used in lean in order to establish batch-size is to first calculate the EPEI (every-product-every-interval) and then compare it to the available time [32]. In the EPEI the requirement for man-hours, machine-time and setup-time is calculated and compared to quantity to be produced during an interval. If more man-hours are committed to the machine than is necessary for the production of parts, that time can be used as set-up to allow for more product variety. As lean setup reduction tools are used for the station even more time will be freed up allowing for more and a larger quantity of setups can be done, increasing the possible product mix.

2.5 Learning organisation

Senge [33] describes a learning organisation as "an organisation where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together".

Knowledge management can be defined by how well management facilitates three parts: knowledge acquisition, sharing and application [34]. To convert this into operational performance Aboelmaged [34] suggest that there is a vital springboard mechanic: innovation performance. This is defined as the technical and administrative routines to ensure the knowledge is put to good use.

Some research also implies there is a difference in how to apply methods of improving knowledge management in SMEs as compared to larger companies [35]. This is explained by the inability to sacrifice employee time for workshops and similar events. However, they saw great results in cases where time was freed for the activities.

Desouza and Awazu [36] lists five distinctive properties of SMEs in relation to knowledge management as the focus on socialisation as transfer mode, the prevalence of common knowledge or an instilled understanding of the bigger picture, the tendency to preserve knowledge through close social ties with personnel and quick training of new employees, the willingness to seek knowledge externally often due to not being able to produce it themselves and the focus on people rather than technology often also stemming from budget constraints in technological investment.

Popescu, Ciocarlan-chitucea, Chivu, *et al.*[37] claims that SMEs have a distinct advantage in the knowledge focused economy of today citing low number of employees as beneficial to communication and policy change while SMEs are also cited to have the benefit of low capital holdings relative to their size. To capitalise on these advantages however a strong human resource development presence in the company is recommended.

To create a good learning organisation Hess [38] names five things which needs to be achieved.

First
Have an emotionally positive environment [38], when that is created some of the biggest inhibitors of learning will be suppressed such as fear of failure, stress, negative emotions and ego defence. One part of creating a positive work environment is the company encouraging bonds being created between the employees where they feel that the relationships are meaningful and they care for each other. It is vital that the employees feel that they are allowed to speak freely and voice their opinion, and that the company works toward mitigating any inhibition which might suppress it, both socially and structurally. Lastly it is important that the employees are allowed to fail and make mistakes, within reason. The employees need to feel safe in the environment in order for it to become positive.

Second
Create more intrinsic motivation and make the organisation more learner-centric [38]. Intrinsic motivation is as the name suggests motivation that comes from within the individual as opposed to external motivation. Fowler [39] distinct further and classes different kinds of motivation into six types with three being deemed as intrinsic and three as external. These are, in order from most external to most intrinsic, or from most sub optimal to most optimal Fowler [39] terms them as:

- Disinterested motivation is when no value is perceived from the activity in question.
- External outlook is when the perceived value of the activity is to gain something external such as power, money or status.
- Imposed motivation is when the perceived value of the activity is to not be a black sheep and participation is thus given to avoid feelings of guilt, shame or fear.
- Aligned motivation is when the activity can be linked to something perceived as valuable, e.g. learning.

- Integrated motivation is when the activity is perceived to have a positive impact on something else in the individuals life.
- Inherent motivation is when the activity is simply perceived as fun or enjoyable.

To achieve this is a science of its own but the major key is to draw employees away from external motivations and into intrinsic motivation [39]. To achieve this a manager should focus on avoiding short term carrots and sticks, monetary or otherwise. One should instead try to impart a sense of importance and purpose in the work, often through the three factors explained in point four.

Third
Organisation should not categorise mistakes as personal failures [38], but view them as a result of bad learning strategies or to little effort. It is important not to punish the employees for mistakes while learning as it might cause the employees to be reluctant towards learning. The mistakes should rather be viewed as part of the learning process where the employee has the opportunity to learn from it. Managers should also lead with by example in this regard and allow the employees to speak freely and honestly without fear of repercussion due to for example having opinions which doesn't align with the managers.

Fourth
Hess [38] and Fowler [39] names three basic needs which needs to be met in order to have a motivated workforce:

- Autonomy - the perceived power of choice of the individual.
- Relatedness - the perceived human connection with coworkers and managers.
- Competence - the perceived skill and proficiency growth of the individual.

These are highly related to the prevalence of intrinsic motivation as opposed to external. To achieve them one must give the employees freedom of action as far as possible to instil a sense of autonomy [39], talk to employees as actual people and take an interest in them as people to create relatedness and finally one must highlight and invest in employees learning and development.

Fifth
Managers and leaders need to act in a manner that creates trust from employees, where they act without hypocrisy and follows the other guidelines[38]. The managers also needs to create a personal bond with their employees where the employee feels unique and cared for.

3 Methodology

The methodology for the research was planned to follow the mixed methodology model where both quantitative and qualitative methods were to be used for gathering data to be analysed [40]. This method gives the "between methods methodical triangulation effect", which increases the accuracy of the results through comparing completely different research methodologies to verify accuracy of results [40]. The different methodologies planned were interviews, observations which represent the qualitative study and video analysis which represents the quantitative study. Further, the use of several case companies was planned to provide the study with data triangulation which will help further to verify the findings [40]. The case companies were chosen on basis of being manufacturing SMEs that have implemented some form of flexible automation technology. The case companies are also chosen because of their involvement in the LoHi Swedprod project.

However, reality clashed with these plans. The problems were twofold: Firstly the realisation was made early that two of the three case companies did not use their flexible automation technology to the extent initially thought. This resulted in problems with booking visits as no suitable production was planned for the close future. The second issue arose with the Covid-19 pandemic which meant physical visits as a whole was now off the table. These two in combination resulted in only one company visit being done with interview, observation and video recording. Attempts were made to get the remaining companies to film use of the robot themselves but this was not possible due to the their lack of robot usage. However, phone interviews were performed with both companies. Observations were not possible.

With these changes as a base the focus of the thesis also moved. The original focus on changeover was replaced with a more general problem identification for SMEs. The results of this is that the one quantitative study that was done and the related interview was done with the earlier focus. However it was still deemed as valuable for the final results and was thus included.

These limitations puts focus on the interviews and to bolster them several industry experts were also interviewed. The experts were chosen because of their common expertise in the field and their diverse background. This means they were all experts on automation with background ranging from academia to sales to consulting.

3.1 Quantitative Study

The quantitative study consisted of a time analysis of the current operations at one of the case companies. The time analysis then served as a basis for determining the current state of the changeover efficiency which is important for determining what problems there are with the automation and what solutions can be found. The time study was based on video recordings of the changeover operations that takes place during the visit. Thus the data was limited to a limited number of recordings which might not be representative of an average situation. Note that this was not the point and that the data was used to identify problems rather than creating any sort of conclusion of the average time distributed between tasks.

The video recording was analysed in two ways. The first way was a simple categorisation of the operator's activities into categories such as time spent on robot, material and machine. The robot category was then broken down further into tool changing, testing, error fixing and software related tasks. This was used to identify potential problems. Secondly an analysis was done with the tool ESEE (Eliminate, Simplify, Externalise, Execute) which is related to the tool Single Minute Exhange of Die (SMED) [23]. This was done to provide the thesis with potential improvement areas in the changeover process and the case companies a preview on the benefits of implementing changeover reduction tools.

3.2 Qualitative Study

The qualitative data was gathered from two sources: A literature study and interviews with both blue and white collar employees at the case companies and with industry and academic experts.

3.2.1 Literature

The literature study was performed to establish and compile the current stance in research on the problems of flexible automation in SMEs. As such, the search phrases focused but were not strictly limited to the following:

- Flexible Automation SME
- Flexible Automation SME Robot
- Flexible Manufacturing SME
- Flexible Manufacturing SME Robot

Literature was filtered on relevancy and where prudent, age because of fastly evolving technologies involved. Since the subject is not well studied, filtering for relevancy meant including most literature that in some form tackled flexible automation in SMEs. The number of such literature was however limited and thus literature related to general automation in SMEs was included. Since the technology is in the forefront of development newer literature was seen as more valuable and older literature was used with caution even though no explicit cut-off age was used. The literature was primarily searched for descriptions of problems related to flexible automation in SMEs. Secondarily the literature was also searched for information on the general problem picture of automation in SMEs. Further some of the same literature was used for theory related to the subject and inspiration for recommended solutions.

3.2.2 Interviews

The company interviews and the expert interviews were similar but with some customisation depending on the interviewee. For instance, when going from interviewing an operator to an automation consultant the question might be changed from "what problems do you experience using flexible automation?" to "what problems have your customers experienced using flexible automation?". This was done to ensure to interview format fit the wide range of background the interviews had.

The interviewees consisted of one operator and one manager from each case company as well as four experts with varied backgrounds in academical logistics, automation sales, automation integration and leadership of an automation company.

These interviews were conducted in a semi-structured manner which provided answers to key points while keeping the interview flexible enough to allow for the interviewee to express points of interest [40]. The interviews were done in two parts. The first part of the interviews consisted of letting the interviewees express what they feel are the general issues within the area of flexible automation in SMEs. This was followed up with asking their opinion on specific issues and themes. These issues and themes were based of problems discovered primarily in the literature study and secondarily in other interviews. The first step is meant to ensure all possible problems come to the surface while the second part is design to go in depth of the problems that seemed common. Before the changes of direction in the thesis the interviewees were asked what they considered to be the main problems in changeover and setup of the movable robot. In addition to these formal interviews everything relevant we saw during the company visit was documented to keep the possibility of finding usable data open.

To ensure interviewees felt completely secure in expressing their true opinions during the interviews we choose to let them remain anonymous, only revealing their general background.

3.3 Analysing the data

To begin summarising and analysing the data gathered in the different studies, the identified problems were divided into categories. These categories held no value other than making cross-examination of the different sources more manageable. The problems from the different sources were then compared if they were supported by several sources. The most significant problems were then identified based on the perceived importance. Based on literature, interviews and the authors expertise recommended actions were then suggested to mitigate some of the critical problems. These solutions are meant to provide stakeholders, especially stakeholders in SMEs, with some ideas on where to begin improving their flexible automation.

3.4 Research Ethics

The biggest potential ethics flaws are misinterpreting the words of the interviewees or manipulating the interviews in way that produces a certain result. To avoid these precautions were taken. The interviewers made all attempts to confirm that their perception of the answers were correct throughout the interviews. The design of the interviews made some manipulation inevitable since talking points based on previous finding were used. However these were kept in mind when compiling and comparing the results to prevent them from gaining artificial importance.

The result and subject matter of this thesis have no foreseeable ethical implications apart from the social sustainability aspects mentioned in the discussion chapter.

4 Result: Literature Study

From a literature review of articles regarding flexible automation, robotics and flexible manufacturing in SMEs many different problems could be identified which in some way either hinder efficient use of flexible automation or hinder the acquiring of automation. The found problems can be categorised into six different types of causes.

- Market - Problems regarding market behaviour
- Strategy - Problems regarding attitudes, mindset and strategy in industry
- Economical - Problems regarding the economical situation of SMEs
- Competence - Problems related to human resources and knowledge management
- Technical - Technical issues regarding the robots or auxiliary systems
- Research - Problems or shortcomings in research on related topics

Some of the problems will however not strictly belong to one category but will overlap into several. For example many of the competence problems could be viewed as economic problems. However this categorisation is primarily used for readability.

4.1 Market

A large problem affects all production but perhaps particularly SMEs is the fact that the market is changing. The market is moving towards a climate favouring smaller batch sizes and higher customisation [41][42][43]. This means there will be more variation in the production and the lower batch sizes will increase the number of changeovers which creates an increased need for flexibility. The large variation in products and smaller order sizes creates uncertainty as it becomes harder to predict the exact products to produce. The problem of uncertainty is especially prevalent in SMEs as they generally have a lot more uncertainty in their environment compared to original equipment manufacturers (OEMs) [12]. The change in market becomes troublesome for automation, as it was created for high volume low variation production [3] and as a result traditional automation technology is often too inflexible to be economically viable in a market with more uncertainty [8]. Fixed robots in general has the problem of not being compatible with an unpredictable market [42]. The higher uncertainty in the market is what creates the increased need for flexible automation technology. This becomes an even larger problem for the SMEs who have even more uncertainty but less resources to handle them [12].

4.2 Strategy

Some of the barriers for flexible automation in SMEs comes from the attitudes and mindsets of their leaders and employees. Management must convince the employees that the changes are good, but the management must also be convinced of the same [10]. The whole organisation must be on board to ensure that changes are implemented well. There is often a lack of top management commitment to the changes, with severe limitation of resources dedicated towards it while simultaneously having unrealistic expectations of the changes' effect [44].

This might lead to even more reluctance to invest further since the first investment did not reach the unrealistic goals. Many CEOs of SMEs do not see the profit of automation as they feel it can not be applied in their company or that their production volumes are too small too implement automation [8]. This is a limitation in how companies see automation and its capabilities where higher management are unaware of the potential that flexible automation brings. This might be because SMEs often lack knowledge in robotics, they cannot properly assess the capabilities of robot systems [45] or predict associated costs [8]. Not being able to predict costs is related to major uncertainty and might further exacerbate reluctance to invest. The level of uncertainty is increased by the fact that many SMEs do not have reliable production data to base predictions on [46].

A common problem in the strategy of SMEs is the lack of long-term planning and short term strategy will often prevent long term investments [46]. Many SMEs will not invest in flexible automation technology due to the high initial cost even though it would result in creating low cost processes [47] which would become more profitable in the long run. With short term planning the layout of workshops will often suffer when automation technology is purchased. Rather than placing it where it is needed, the automation will often be placed where there is extra space [43]. The poor planning and placement of the cell will in many cases create an inefficient and complex material flow [43]. The problem becomes even harder to handle for SMEs as many of them will do the planning manually. Small companies tend to have a lack of specialised management such as supply chain manager, IT and CFO. This can contribute to the focus on short term strategy as management do not have the deeper knowledge to make long term plans in all aspects of the company. Another reason for focus on short term plans is that many SMEs do not have reliable production data to base predictions on [46] which makes it hard to make accurate long term plans.

Another strategic problem is the common choice of relying on external parties for design and knowledge of their automation systems[47]. Chen, Xiansheng, Benoît, *et al.* [47] claims that there are often problems when external designers create the SMEs' flexible automation systems. In their survey, the belief that the external party will be unable to capture the SME's need was listed as one of the top three reason why SMEs have not invested in flexible automation technology. When designing the robot system the external parties will miss aspects due to unfamiliarity with the company's production system. The SMEs will also often be unable to properly establish the requirements of the systems and in many cases there is a lack of experience with automation or general low engineering knowledge which will result in the requirements becoming too informal or infeasible. With the informal requirement there is a much higher chance of the designer misinterpreting.

There seems to be a general conservatism towards robot tech in India. Bad press through other failed Indian project further this attitude [45]. This is probably enforced by the fact that Indian SMEs perceived robots to be too expensive and a fear of robots stealing jobs [45].

4.3 Economical

When buying automation technology the investment cost is a big hurdle for many SMEs[3]. It is not enough to just buy the robot, there are many other types of equipment that needs to be purchased in order to create a functioning cell. In the case of flexible automation even more specialised equipment is needed, for example inputs that go into the tools such as sensors, cables, connectors, NC code loaders, processors, flexible couplings, drive packages, special bearings etc [42]. There is also an added investment cost of integrating it to ensure safe communication between the different components. In a survey of Chinese SMEs by Chen, Xiansheng, Benoît, *et al.* [47] among the most common reason for SMEs to not invest in automation technology was the high development cost of the system. The high initial cost creates a large barrier as SMEs typically have severe resource limitations [12]. Generally small companies do not have the resource to capitalise on new more efficient opportunities [10], this creates a barrier which makes many smaller companies unable and unwilling to follow the trend of increasing automation.

The companies surveyed by Chen, Xiansheng, Benoît, *et al.* [47] also names high maintenance cost as one of the three most significant reasons to not invest in flexible automation technology.

4.4 Competence

When it comes to purchasing and operating, SMEs' cost and availability of competence is often cited as a large barrier. For example, European SMEs say that cost of and lack of human resources is their biggest business constraint overall [48]. This problem affects automation heavily and flexible automation even more because of its novelty. In Poland there is both a distinct lack of operators who can handle the complex modern manufacturing systems and a lack of automation experts [10]. India also suffer from this issue where there simply are not enough operators capable of running the robots [45]. This seems to hold true for Europe as a whole too, where the main barriers for SMEs to invest in industrial robotics are investment cost and lack of competence [48]. Furthermore this problem is worsened in poorer countries, especially in free market regions such as Europe where professional mobility is high [10], because of the fact that people with competence tend to take it abroad where the pay is better. This leads to a cycle where these countries hire expertise from even poorer countries and thus robbing them of competence as well.

The lack of competence also often leads SMEs to source their knowledge externally in the design and installation phases [47]. All of these problems stem from the fact that operating industrial robots is complex and requires expert knowledge in robotics [8]. Indian SMEs for example report low technical knowledge outside of core business, low awareness of technological development and low standards of education [45]. There is also an issue keeping up with new technology which often is a competitive advantage or even a competitive qualifier in some fields. The issue is that most new technologies come with an investment cost in technical skill which does not exist in-house [42].

One explanation in the lack of in-house competence of SMEs might lie in the fact that SMEs have a hard time formalising and sharing competence internally. There is a lack of knowledge about automation methodologies causing difficulties in identifying best practices [41][12]. The production knowledge that is present in SMEs is seldom formalised in a way that allows integration in the system [8]. This formalisation of implicit production knowledge into engineering specifications or robot programs is difficult and is therefore not always done [8].

There is also an issue with creating task descriptions which are maintainable and flexible enough to adapt to changes in production processes during a product life cycle while also satisfying safety demands [49]. Furthermore, smaller enterprises often lack dedicated personnel which can maintain the robot cell [8]. Planning in many SMEs is often done manually [43] which might further degrade integration of IT systems.

4.5 Research

When it comes to research within the field of flexible automation in SMEs, there are some issues. For example only 6.5% of research on flexible automation is done within the context of SMEs [11]. Furthermore automation research in general has also been focused on large size enterprises rather than SMEs [43]. This means that there is a relatively small pool of research on automation in SMEs in general and flexible automation in SMEs in particular. This is problematic due to the differences between both management structure and operational conditions in an SME as compared to a larger enterprise. This means that the knowledge is in many cases not translatable to SMEs. Knowledge of traditional automation technology will in many cases not be applicable in SMEs due the them working with the high variation and low volume as opposed to what automation was designed for [3]. The lack of research dedicated to SMEs becomes a problem as individual SMEs with very limited resources are unlikely to fund further research. The result of the low level of research will most likely be SMEs trying to adapt traditional automation in a setting where it will not be efficient.

4.6 Technical

The first technical problems discovered in the literature was issues regarding programming. Current robot programming techniques are not suitable for frequent changes of often highly customised products manufactured in small batches [8]. One of the reasons are PLCs which due to their real-time execution and state based design have a low abstraction level of programming and often fail to support high-level programming which prevents efficient re-use, maintainability and structure of code [49]. Furthermore teaching methods are shown to be time consuming and imprecise [50]. Some evidence suggest this trend is strong in India where programming being too time consuming is seen as a barrier [45].

The second technical limitation is the mismatch between current robot systems and requirements of SMEs. One trend standing in the way of flexible automation in SMEs is the fact that robot development generally has been geared towards high volume, mono-task robots [45]. SMEs are also often stuck with old machines which they can not afford to replace [10]. This results in many robots having a capacity far higher than the machines they serve [10]. Thus SMEs have to invest in performance they do not use or take on debt to upgrade the old machines.

Löfving, Almström, Jarebrant, *et al.* [3] says there are several hurdles to overcome to allow robots to be used in a flexible manner in low volume, high variety manufacturing: time consuming programming,lack of flexibility, safety concerns and mobility problems.

Regional studies show that in India robots are perceived to be too heavy and inflexible while Indian SMEs also report a lack of processes to automate [45]. Classical robot cells with fences also take up more space than comparable manual work-station [8]. This effect might be limited with flexible automation but has in the past prevented automation in SMEs.

Further technical issues involve vision systems have trouble properly identifying edges due to reflection [12] and system communication where most components in an automation cell has different preferred communication protocols which can force signals to be sent several times through different busses or the signals need to be translated thus reducing efficiency [12]. There is also a lack of integration towards programs to support the automation which makes it inefficient as material and information flow will be delayed [42]. This causes difficulty in automatically starting any process because the necessary data is not available to the robot. In a fully automated production line operators have to spend a lot of effort to ensure that the location uncertainties of the robot, tool and work-piece are corrected [8]. These problems become exacerbated by having more moving parts.

5 Results: Case Companies

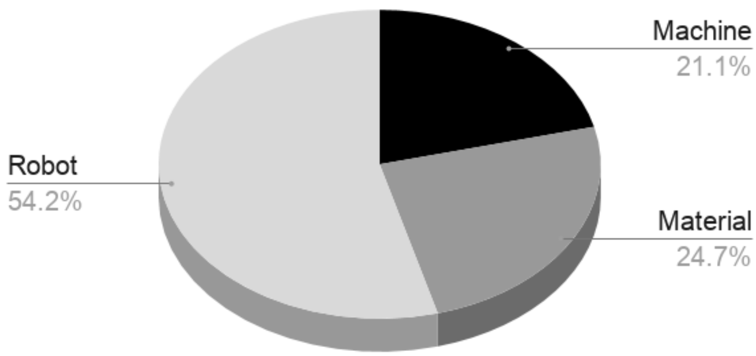
The following chapter outlines the problems identified in the case companies. Results from case company 1 includes both interview and time analysis while case company 2 and 3 consist of interviews only. All three companies were a part in the previous thesis [4] and uses a movable robot. The robot is a industrial robot arm attached to a platform which makes it movable between different docking stations [51].

5.1 Case company 1

The company has a machine park where they process with sheet metal. They have several machines for bending of the metal, they have a few stations for drilling holes and a few station for varnishing the metal. The company works as a contract manufacturer, where other companies outsources some manufacturing to them. In the production, there are currently two robots, one fenced and one fence less.

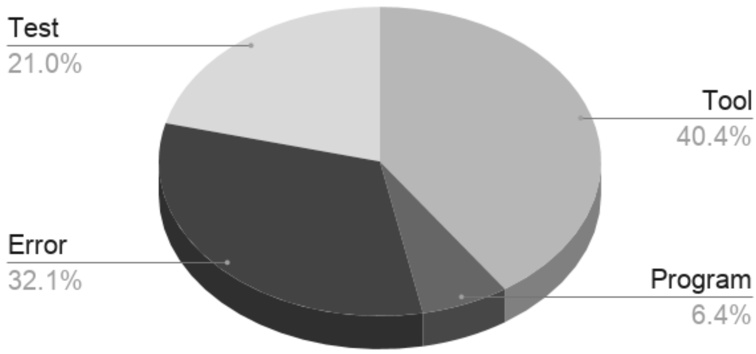
5.1.1 Video analysis

Case company 1 is the only one where it was possible to visit the factory and film the changeover process. Therefore the video analysis is done only at this company. The video was recorded during a changeover between two different products using different tools. In total the changeover took 29 min and the time distribution can be seen in figure 5.1.



Figur 5.1: Main components of operator time study

The activities during the changeover can be categorised into three main type of activities. **Machine** is the time spent on setup for the bending machine. **Robot** is the time spent setting up the robot, including tool change, and a test run with it. **Material** is the time spent on material handling.



Figur 5.2: Sub categories of the Robot component in the time study

The robot category can be further divided into sub categories, see figure 5.2. **Tool** is the time it took to detach the old tool and attach the new tool. **Program** is the time it took for loading the program. **Test** is the time it took to do a slow test run. **Error** is the time spent on error handling.

The time analysis shows a problem with unrobust operations which results in small but time consuming errors occurring. It also showcases how significant the tool change is in the changeover process.

From the video other problems could be discovered. For example there is no externalisation of the changeover, nothing is done while the machine is working even though it would be possible, but instead the entire changeover is done at once. The material handling could to a higher degree be done by the robot, but instead it is done by the operator. There seem to be no standardised method for doing the changeover which will thus likely vary in time between different operators. Without standardisation it is also generally harder to do improvement work [23]. The video showed potential for improvement, for example time could be saved if a tool changer module was added to the robot.

The material did not arrive with the correct orientation and therefore the operator had to manually re-orient the material which included flipping of the metal sheet. There was also a change in pallet. They used a specialised pallet for the in-material of the machine which had the added functionality of locking material in place and easy placement of support material. The pallet change did however take some time.

5.1.2 Interview problems

An interview was also conducted with a operator and a production manager. They did not consider changeover to be a major problem but would still like some improvement especially in the time it takes to change tools. They were not overly concerned about determining minimum batch size either, limiting it to approximately 15 units and based this equation on experience rather than calculation. The lack of focus on the changeover could be because they only use the robot about 2 days per month. Something they had more trouble with was the limitation in maximum batch-size. Due to space and programming limitation the robot can't run unsupervised for more than an about an hour before the out pallets need to be changed.

Introducing new product variants was a far more significant problem for the company. Due to the geometry of their work-pieces, their robot grippers were incompatible with many of the products. The problem generally stemmed from them using vacuum to lift the metal sheets but many of the sheets are full of holes which severely limits the lifting power of the tool. They would like to have more tools but are limited by the high cost of making them. They have trouble integrating the development of the tool into the commissioning for the customer as they want to do it as quickly as possible. This has resulted in the robot having few tools and it is therefore unable to work with most products.

Another barrier for the company in more utilisation of the robot is the programming. It takes about an hour to create a program for a new but similar product, but it is not being done. Making the new programs seem to rest on the initiative of the operators of whom there are only two who can do the programming and at least one of them feels there is too much other work for him to have time to program the robot. As a result more products could be produced with the robot without getting new tools however they lack the robot programs for the products. The program interface is made by a smaller supplier which intends for the program to be used by operators rather than robot programmers. The program is considered to be generally easy but the simplification creates limitations in the functionality. The larger degree of safety needed due to the robot being fence-less is also perceived as constricting.

The company was very reliant on the supplier of the robot. A large part of the programming was not available to them which made them unable to create or change the robots paths. The supplier handled the installation and safety certification, this made the company unable to make any larger changes, or introduce new elements to the cell without the supplier. The heavy reliance on the supplier is probably further complicated by the supplier being located five hours away from the company.

5.2 Case company 2

Case company 2 is a subcontractor with a focus in cutting operations, especially high quality products with small tolerances. The company is a manufacturing company producing components on a contract basis, with sheet metal of different kinds as main raw material. They are part of a larger corporate group which technically disqualifies them from the SME segment. Since the sub-companies are fairly operationally independent the assumption will be made that they can be treated as separate entities thus qualifying them as SMEs for the purposes of this thesis. The company uses flexible automation in the form of material handling in and out of a press brake machine.

A visit to the company was not possible due to the aforementioned Corona-related limitations. No relevant production was scheduled so filming of the process was not possible. The data gathering was thus limited to a telephone interview. The interview was done simultaneously with a production technician and an operator with some experience running flexible robots.

The interview revealed a couple of problems pertaining to programming of the robot. The problems were related to a specific programming interface are omitted where they are not thought to be general. For instance programming at the case companies required full overview of the whole process before beginning due the specific software not allowing editing programs.

Further issues with programming are all related to time consumption. With a changeover programming time of 30 minutes and programming time for a new product of a couple of hours, the flexibility ought to be severely limited.

The unloading is the primary performance limiter as far as long unassisted runs are concerned and programming the unloading phase is seen as critical and limiting. This is due to the limit in the robot's ability to reach which caps the maximum number of outbound pallets at two. However, with some combinations of tools and articles this is negligible as the company have run as many as 210 pieces in six hours without human interference.

As far as articles are concerned, geometry is more often a reason not to run the article with automation technology involved as opposed to a performance inhibitor. The geometrical variable in question is holes and the trend is towards more holes meaning a more difficult article to grip with the robot.

5.3 Case company 3

Case company 3 is a subcontractor focusing on forming sheet metal through pressing, cutting and rolling, they also perform welding and machining. It is a small enterprise with about 30 employees.

Case company 3 experiences several problems related to cost and economics. The main issue is that their flexible automation has a too large initial cost and setup time to justify using it for most of their products. Most products require unique grippers and grippers cost somewhere between 20 000 and 150 000 SEK. This alone means that the products needs to have a sufficient series size and yearly volume to offset the tool cost. The company requires a minimum batch size of 1000 and series size of roughly 5000 to consider the product viable for automation. They generally wish to pay of the tool within a year which by their estimation requires a yearly volume of somewhere above 5000-10000 units. These demands coupled with a high uncertainty regarding future orders makes using the flexible automation technology infrequent as it cannot be justified economically. Customer behaviour plays a role as well here with JIT strategies pushing batch sizes even lower. The company also has limited power over product design, especially design changes for easing robot usage. Furthermore, customers are often willing to share the initial cost of the pressing dies but not the robot grippers.

The need for unique grippers for each article is explained by the lack of flexibility in current grippers. Adjustable grippers exists but infer a gripper setup time of up to an hour. Another problem with grippers is that they cannot compare to a human hand in terms of dexterity. The fact that products often have different shapes after the pressing process makes grippers even less efficient. Grippers, or rather how the robot position grippers, also prevent the use of pallet collars which might cause problems in downstream processes.

Another thing the interview highlighted is the danger in seeing automation as being operational out of the box. The interviewee perceive auxiliary preparations as a large concern and something that takes a lot of time. For instance something as simple as some material having to be removed from the press during the process might cause issues, especially with the simple programming interface their flexible automation technology solution entail. Another example is lubrication which is easily done by an operator with an oil dispenser but is much harder to automate on the fly. Sheet separation is also a common issue which the simple interface of their current flexible automation cannot handle, i.e. if two sheets are accidentally lifted there is no way for the robot to reverse its error. Problems of this kind means that a lot of preparation is necessary to make the robot work well, whereas a human operator can handle such problems without much difficulty. The company says they would be willing to pay for an external automation partner to sell solutions to these problems as part of their offer.

When it comes to competence, the company only have two people able to program their flexible automation technology but since they only run it with two articles they deem it sufficient. The company does however have advanced robot programming expertise with other software. The programming is described as limiting due to the simple programming feature included in their current flexible automation solution. The solution also includes a safety zone which is cited as taking up even more space and limiting operator movement even more than a fenced solution. Further the company states that they try to improve their knowledge about all processes and systems, but lack the resources to add dedicated personnel, and therefore much expertise regarding automation is outsourced. Improvement work is done but without an explicit structure.

6 Results: Experts

In order to become more familiar with the problems for SMEs with flexible automation several experts were interviewed. They were asked in a semi-structured interview what they thought were the most significant barriers for SMEs to efficiently implement flexible automation and how the barriers can be circumvented. The authors then asked for the experts thoughts on the different themes and problems. The interviews are summarised and presented in this chapter.

6.1 Automation Expert

The automation expert has experience in installation of flexible automation technology. The interview however took place before the restructuring of the thesis and had a larger focus on usage of the movable robot from the previous thesis rather than flexible automation in general. Some of the interview were still usable with the new focus but not all. From the interview several different problems were identified.

The industry is in many ways very conservative resulting in companies being unwilling or afraid to change. This has become very evident regarding the movable robot used by the case companies, where there seem to be resistance from all levels of the company, not just the ground level people. The lack of a fence is something they find rather scary so the management is very concerned with the safety of the people near the robot. They often believe it to be an uncertain element in the workplace and something which can create a great liability. Today robots are somewhat commonplace in industry so the conservative attitude towards them have somewhat disappeared, however with the new fence-less robot it is still very much real and a barrier for the industry. Fence-less robots do not otherwise have any significant drawbacks beyond the slightly slower production speed compared to the same robot with a fence. In the case of the movable robot the safety systems works well, but the attitude towards the robot is the bigger problem.

The conservative attitude towards new technology is not always unfounded, many companies have tried many new things and have failed, this has created a reluctance towards adopting new technology. There is never a guarantee that the new technology will succeed and become useful which makes it hard to sell things like the movable robot. However he still believe the conservative attitude and fear are the main barriers in the industry

There is also a problem with lack of knowledge at companies, which stems from an improper education. This leads to the robot not being utilised enough. It also shows in production when someone who is not used to making robot programs makes them, it can even significantly reduce the efficiency.

A more technical problem he experiences in the role as an installer of robots is problems with the signal exchange between the robot and the machine it serves, especially with older machines. In order to have a working robot station the robot needs to be able to control the machines around it but sometimes the signals uses different interfaces and can not be processed by the different machines. When this situation occurs the signals will need to go thorough a unit between the machine and robot which can translate the signals in a way that satisfies both. The process of doing this can be complex which is why there is a need for skilled automation technicians and it can become a safety issue if the signal exchange is not done properly as the robot and machine becomes unaware of each other's actions.

On the topic of improvement work he believes it needs to come from the management. The movable robot has a lot of potential for improvement as it has the advantage of having a higher capacity for usage, which should lead to higher flexibility and shorter lead-times. There is also the problem of "hemmablindhet" which is Swedish and translates to home blindness, which is when you do not see the flaws in your home. Many companies will not see the flaws in the workplace resulting in many unnecessary operations occurring. For companies to improve it is important that they start seeing these flaws.

Support tools exist for more efficient flexible automation which can be things like vision systems or vibration sensors. He has seen a clear increase in the use of vision systems but each installation of a robot in a production system is somewhat unique and will require different support tools, there is no one solution for all.

6.2 Automation as a service CEO

The second expert interview was held with a senior executive of an automation company offering flexible automation as a service. This interview therefore comes with the caveat that the interviewee represents a company offering automation as service which would be a stark contrast to many companies' situations and a solution to some of these issues. This interview highlighted a couple of perceived problems.

To begin with, some problems regarding attitude and mindset was discussed. The interviewee has seen a wide spread assumption that automation investment means large, fixed and mono task robots. The interviewee says that this leads to corporations not having established decision processes to make a new kind of automation investments. With the improvement of robot flexibility and the emergence of different business models there are more possible solutions than ever.

The interviewee thinks there is a fear towards automation and robots in the industry. He thinks there is always a fear of the unknown and uncertain. The operators might fear the novelty of a robot working near them without a fence between them and the robot. For management this might be the many unknown variables of implementing automation combined with the high investment cost which makes it a risky investment. In order to make use of the new technology in an efficient manner they need to be able to make decisions outside of their comfort zone and question their conservative instincts. With increased use and familiarity towards the robot the fear is expected to decrease.

Another issue is, according to the interviewee, the relationship between successful implementation of other management systems and successful implementation of automation technology. This means that a company with good methodology in place to plan and control what goes on in their operation will be a better candidate for automation compared to its less methodical counterparts. Examples of such operational methods which might benefit automation includes lean programs, continuous improvement systems and generally keeping a well organised factory. There is a problem in some companies where they do not properly understand their processes, and there is a lack of knowledgeable process and production developers.

The next problem discovered is related to corporate habits with regards to operation planning. According to the interviewee, one problem within many companies is that there is a budget for automation and a separate budget for staffing, even though both have the same objective: to ensure operational success.

The last problem category pertains to the expectations of integration and general performance of automation technology. The interviewee makes the point that no one would hire an operator and expect them to be completely in tune with operations and perform optimally their first day yet that expectation is common when buying automation. Companies are prone to expecting complete integration where it might not be necessary and have low tolerance for learning about and troubleshooting their new robots.

The interviewee thinks the biggest problem is in the decision making. There is a tendency to not really look at a long term perspective and plan with flexibility in mind. In many cases the company will purchase a robot for a very specific task, but sometime in the future the task might become irrelevant due to product changes. When this happens many companies end up with a robot but no task for it, and no new tasks for it on the horizon which results in it not being used. Another problem which is on the opposite end of the spectrum is automation technology being purchased without any plan. The interviewee thinks that the companies are often enticed by "flashy demos" rather than having a task which will be solved by the usage of automation which will in many cases result in the robot not having a task and being underutilised.

There is also a problem with lack of experience in automation, some companies do not understand the complexity of implementing automation and will expect it to be easy and profitable. The lack of experience will make them unaware of its utility as a result there is no plan or goal for the robot. The companies are not aware if the automation is supposed to lower cost, improve work environment or increase production. This creates cases where automation becomes the solution because it already exists but the most efficient solution would perhaps not involve automation.

There is a problem with integration of signals especially with older machine parks and there is a lack of competence to solve the problem. There is also the question of how much to integrate. Full integration is not always necessary for flexible automation technology to work efficiently and sometimes the same result can be achieved with partial integration. Furthermore all integration does not need to happen at once, it can instead be successively increased.

6.3 PhD working in Academia

The third subject interviewed is a PhD working at a university with focus on management of production and production logistics. He has researched flexible automation in industry with a focus on internal logistics.

The automation technology which exists in industry is mainly stuck on the concepts of traditional automation which is lacking in flexibility. Automation is often dedicated to a certain route in the case of AGVs (Automated Guided Vehicles) or a certain process for robots, but it is not used outside of this dedicated task. It works well with higher volumes but creates a problem when they have to determine and achieve profitability with production of lower volumes, as it generally will require more and faster changeovers. A system which have the abilities to handle deviations and a larger product mix is often more complex as there are more scenarios to take into consideration. The higher complexity will generally be more expensive which makes it harder to achieve profitability of the investment. The difference can be an AGV having a certain route to follow where it runs the same tasks versus having a list of tasks which gets assigned as the AGVs become available.

A common problem for companies is determining the level of automation. A company could try to implement a complex system which can handle any problem but the cost will become large and the system will not become profitable. The interviewee stresses the importance of the companies asking themselves the following questions:

- When is it appropriate to automate?
- Which parts of the surrounding systems are easily integrated with automation?
- Which parts of the surrounding systems are hard to integrate with automation?

Getting started in solving this and implementing automation technology in the production system can be hard, they also have to determine what supplier to use how much to invest etc. The choices become especially troublesome if the company is unused to automation, the suppliers will in many cases try to sell a more advanced technical solution which gives them more profit. This sounds cynical but might often be because of uncertainty in automation technology performance and thus a "better safe than sorry" approach is used. The client however generally want a solution which is as simple as possible in order to minimise the cost. If this part become too overwhelming it might stop companies from wanting to pursue automation.

There is also a problem with lack of application competence among the suppliers. The suppliers will have great technical competence but will often lack competence in the production system of the client. This makes it hard to determine where their great technical competence should be used. The clients are usually in the opposite position, they have the knowledge of their own production system but lacks the technical competence which makes it hard to determine what is feasible and some opportunities are likely to be missed. Clients and supplier will have the problem of determining who has what responsibility and need the competence in both areas in order to determine who is most appropriate for solving what task. This becomes especially challenging to do when the relationship between them is shorter as when the client only uses the supplier for a single non-reoccurring product.

Getting the technical competence can be very hard for the companies. The automation technology will often be underutilised or not used at all because there is not enough knowledge about the system. At the same time they will not get the knowledge because the system is not used enough, creating a "catch 22" situation. Many companies will solve this by getting the equipment at a very low scale and use it as pilot to experiment with it in order to get insight into the technology. SMEs are often limited in this approach as they often do not have the capital to buy technology for experimentation. They also do not have the resources to dedicate people towards the technology in the same way larger companies can. A larger company will often have people dedicated to the technology who only work with gaining knowledge about the technology and how to use it. Doing this will generally not be economically viable for smaller companies.

Most companies start with using the automation on a smaller scale. A problem from this is that the companies try to determine the capacity of the technology before having gained the competence to use it efficiently. As a result some companies will prematurely abandon the technology as the result was not what they wanted. Another problem which is common when starting on a small scale is when they want to take it to then next step and scale up the use of this technology. When scaling it up it will become far more complex and very hard to implement efficiently. This problem might be amplified by the fact that a lot of companies will do the small scale production with the new technology on a simpler process. As a result many companies will not be able to get past the trial stage with the new technology.

There are also some attitude problems towards robots and AGVs. There is fear of them due to unfamiliarity which creates the challenge for the companies of creating a feeling of safety for the people working with the robots. The feeling of safety also needs to be extended to the people working in the surrounding of the robots. A truck operator might not have as much interaction with the robots and AGVs which might hinder the feeling of familiarity resulting in fear instead. Another important fear to take into consideration is the people's fear of being replaced by robots. To solve this companies need to work actively with familiarising everyone with the robots.

If the robots are not accepted by the people it might have a detrimental effect for the robots' production. If the people do not feel comfortable with the robot or feel that it does not provide worth they will in many cases not give the robot the support it needs. In some cases they might even try to sabotage the robot, this can be done by creating some deviation which it can not handle which makes it stop production. Even if the people are not sabotaging the robot, a more common problem will occur where they ignore the problems the robot needs help with. For example if a small object is blocking the path of the AGV the people will be less likely to remove the object if they are unaccepting of the AGV. As a result it will become hard to get efficiency with the robot and AGV. Companies therefore need to create a feeling of ownership towards the robot where they feel familiar and responsible for their result.

Another common problem with the perception of the robot is the amount of problems reported. If someone sees a coworker making a mistake they will most likely tell them to not do that without creating any documentation, but if they see a robot make a mistake they will report it. This created a skewed perception where the robot seem to be having far more problems compared to people. This might create fear or make management look negatively towards the usage of the technology.

There is a large problem with the physical interfaces in flexible automation technology. Not every material will be delivered using the same type of container, the most common in industry is the EU-pallets which can be handled by a forklift upgraded into an AGV. If the material is transported in for example a small plastic container different tooling is needed to move it. Since it will be very inefficient to only transport one small plastic container per delivery, several needs to be delivered at the same time which creates the challenge of needing to coordinate what should be delivered where and in what order. The problem becomes more complex the more flexible the system needs to be. Every container also needs to be delivered with sufficient precision especially if a robot is going to be using the material as they generally do not tolerate a lot of deviation. There is also challenges when the material moves from one automated process to another as the out material need to have an orientation which the next process can handle. If there are many automated processes and no humans, the deviation handling becomes even harder. If there is a human in the environment, they can generally fix the problem which caused the robot to stop, but if there are no humans, the ability to handle deviations need to be even greater.

Another type of integration problem is the communication between devices and with ERP programs etc. The more technology the more complex it will become to get everything to communicate with each other. The problem is even more significant if old machines or planning systems are used. They will be less likely to follow modern standards of communication and will often instead need a plugin to perform its tasks. This means there is another subsystem which needs to be taken into consideration in the communication chain which will probably increases the system's complexity.

6.4 Sales manager

This expert is a sales manager for a large company's system/robotics division and has experience working in helping companies make their automation journey. The automation journey is the name the interviewee gives to the process of implementing and operating automation effectively and everything that entails.

Smaller companies often lack the competence to start the automation journey. The lacking competence can be in robot knowledge but also the higher level of production knowledge. It can sometimes be insufficient knowledge about their own production where the requirement specification is lacking. It can be seen in things not being properly defined and them not holding their production to standards specified in requirements. The missing requirements can be things like tolerances and quality, they often need a more clear picture of their product. The problem will generally not be as prevalent for sub-contractors as they produce someone else's product which has these requirements established.

There is also a challenge in deciding how to start the automation journey once they have decided to do it. It is often not possible to hire the necessary competence for a smaller company so SMEs will have to rely on an external party such as a supplier or robot integrator. It is hard to determine who to use for implementing this, which seem to be a barrier for some. Some of them feel that they can not find the relevant competences, if this becomes a problem the company needs to ask themselves if they are limiting themselves or if the competence does not exist where they are. In Sweden the knowledge is generally available but many companies will not pursue automation unless they are contacted by the automation companies, they seem to not want to take the initiative to look for the opportunity themselves which The Swedish Agency for Economic and Regional Growth seem to agree on.

Companies need to have the vision to make the change, and look at the long term perspective. They often feel that they do not have the time to pursue it now, or that it will not work for them. When they are showed other companies who have managed to solve similar problems through automation they often change their perception of automation's feasibility in their own company.

It can be hard for SMEs to bridge the gap to the knowledge needed to work with a robot integrator. The SMEs will often not have sufficient knowledge at hand, where they do not know their logistical flow, tolerances of processes or how to make the product compatible with automation technology. It is therefore very important that the SMEs make a pre-study before getting the automation technology and to get some basic automation knowledge. It is often too hard to put responsibility of knowing the companies production on the suppliers, therefore the SMEs need this competence themselves. Sometimes the knowledge in automation which would make them able to make a calculation of the investment is lacking, they do not know all the costs or how to use it and its potential. Therefore it is important to gain some competence early on. The big costs are not the robot, it is the engineering around it and adjusting it for different customers. Things like tools need to be carried by the products cost calculation even if they can be used after the product is no longer produced.

The development of the necessary competence is often something the companies do not know how to pursue, it is in the interviewee's experience something the external consultants will have the tell them. They generally outlines a plan for what step the companies need to take in order to achieve the necessary competence. There exist no general guidebook for them on how to do this as there are many different factors which makes it hard for them to determine how to reach their goals. This makes them very dependent on the suppliers. Generally the ones who succeeds are the ones who manage to recruit someone who already has experience with this type of work. Otherwise they will generally have to rely on suppliers or consultants.

Comparisons with the big automated automotive industry are not appropriate since other industries, and in particular SMEs, have completely different circumstances. where much of the knowledge will not be applicable. Many SMEs are subcontractors and have little to no control of the market and will be very reliant on the client making a timely prognosis which can create uncertainty. Some SMEs will however have more awareness and control of the market, but it is harder for the subcontractors.

SMEs might be a bit conservative as they are often sub-contractors working with other people's products, meaning they are not really innovative companies. This probably makes them more risk averse and will try to have more of a safe production. There are examples of failure in implementing automation technology where larger companies are not able to solve the problems and the SMEs fear being in a similar position but having even less resources to solve it.

Some SMEs do not have the capital to make use of opportunities. Now during the pandemic there are several companies which are looking towards automation as they would then be less dependant on humans who get sick. For some SMEs they can not capitalise on the opportunity as they can not afford the normal return of investment time of 1-3 year. Borrowing money is easier today than before, the interests of loans are very low making the investment easier today.

It is always difficult to integrate automation technology with old equipment, not only from the perspective of effective usage of the machine but also the safety aspect. It can be hard to assure the safety of the communication, which SMEs are often unable to do. Even the suppliers will sometimes not be able to do this as it is a commitment but they are unable to guarantee the safety. SMEs need a supplier who knows regulation and signal exchange to make integration possible.

There is less fear today compared to when robots were introduced in the 70s. There are machines which perform tasks that are more likely to take the jobs, such as computerised numerical controlled (CNC) machines, than robots as the robots are often doing jobs which no one wants to do either way, like material handling. But of course it can be a problem if management do not bring the workers along with them on the automation journey. Management on the other hand are often too prone to taking risks as they sometimes work with too old machines which are not in line with the government's recommendations.

More research is needed in how to interpret laws and regulation for practical automation usage. It is hard to make the risk assessment, which is the core of the safety certification. It is dependant on many different factors including the product, tooling and environment as well as the education level of the operators. There are too many situations to make anything general which makes it hard or impossible for institutes to do this research.

7 Results: Comparison

This chapter will cover the combination of the problems found in the literature study, expert and company interviews and the company visit. The literature study is viewed as the most general source and the interviews as support for specific issues. The problems will only be compared in this section if it is supported by multiple sources. The problem not being present here does not mean it is not a significant problem, but rather that there are differing perspectives on the problems. Some of the problems are paired together as the authors believe they are describing the same problem in different ways.

The comparison is structured according to the following strategies:

- Market - Problems regarding customer and market behaviour
- Strategy - Problems regarding attitudes, mindsets and strategy of companies
- Economical - Problems regarding the economical situation of SMEs
- Competence - Problems related to human resources and knowledge management
- Technical - Technical issues regarding the robots or auxiliary systems

7.1 Market

The literature claims that production is moving more towards customisation with more variation and lower production volumes. Most interviewees did not explicitly claim the market as one of the problems that SMEs are facing, but all the case companies have some degree of problem with orders being too small to be used with their flexible automation technology. One case company did however corroborate this blaming the more widespread use of JIT as the reason for customer requiring smaller and smaller batches.

In the literature several sources claim that the uncertainty in the market makes SMEs unable to follow the structure of traditional automation as it is too inflexible to handle uncertainties. None of the interviewees have claimed the same reason as to why SMEs can not copy the structure of larger traditional automation. Several of the experts have however stated that SMEs and their need for higher flexibility is incompatible with traditional automation, without making an explicit connection to the higher level of uncertainty SMEs are facing.

7.2 Strategy

Two experts and the literature believe there is a fear towards change and the unknown which is applicable during the process of introducing automation. They do not seem to think that there is a general fear towards robots, one expert claims there is less fear towards robots than ever, another expert believes that people find the fence-less robots scary. Both the literature and experts believes it is very important that those who work near the robot are brought along with the change so that they can accept it. The case companies make no special mention of fear towards change or robots.

There are some experiences of conservative attitude from SMEs. One of the experts believe that as many of them are subcontractors they are not very innovative and will try to do what is safe. Another expert believes the attitude is a far bigger concern which can be seen at all levels of the companies, and describes it as something which is a serious barrier against their automation journey. In the literature there were similar concerns, at least in Indian SMEs which had a conservative attitude towards robots in general.

Many SMEs rely on external parties which has been shown true by all interviewees. Literature describes problem with the cooperation between the ones who want to automate and the suppliers, which two experts also mentioned as problems. One expert belies there are too few formalised requirements which gives the supplier or integrator insufficient information to work with, this is also supported by the findings in literature.

Literature describes lack of long term planning as a serious problem where robots are placed in the factory without a long term plan or where short term success is favoured over the long term. One expert believes this to be a key problem where companies purchase automation technology without having a proper plan for them, which generally result in the robots being under-utilised. Another expert claims that companies often purchase the automation technology and then use it experimentally without planning or knowing how to scale up the automation, which can also be seen as more focus on short term than long term. Literature suggest that the problem is based on the poor reliability of their production data which makes them unable to make long-term plans.

Both expert and literature argue there is poor production data. This can be insufficient as a basis for decision making.

Literature assert that management have a tendency to not give the change enough resources but still having high expectations of the outcome. One expert agrees that this is how management tends to act when introducing changes in general. According to one expert a problem is that the budgets for automation is generally separated from the staffing even though they are supposed to solve the same task. In one of the case companies there was an example of this problem where they expected operators to make new programs at their own initiative but did not seem to dedicate special time or resources towards this goal.

Companies have too poor understanding of automation before the investment. Literature states that companies often do not have this competence and are thus unaware of its capability and the technological development of automation. Many experts agree that there is a big problem in companies not having competence when they purchase the automation technology as they often do not know what the objective should be for the automation technology or to what degree the automation should be done. Companies are also not aware of the problems they will face with several of them expecting the automation technology to work at full speed as soon as it is implemented according to one expert.

One expert asserted that the SMEs often have problem with the improvement work, they become used to how things are and do not see problems. Another expert claims that they often improve until it works well enough and then it is in many cases forgotten. Of the three companies in the study only one had a structured way of working towards improvement.

7.3 Economical

Literature describes the initial cost of automation as one of the biggest hurdles in SMEs. Experts agree that it is a large investment with a lot of uncertainty which makes many companies assess it as a risky investment. One expert believes it is easier to get loans for theses investments today but not all companies, especially smaller companies, can afford to wait for a payback of several years.

Flexibility is often very expensive. Flexible automation technology is generally more complex and the more complex it becomes the more expensive it also becomes according to one expert and literature. One expert claims the largest costs in automation is the engineering and adjusting it to the customers need. This can for example be buying new tools to produce another product or customising the automation technology for other product changes. The cost of new tools is a big barrier for two of the companies in the study. Their current tools are unable to service enough product types and buying new tools is too expensive, resulting in the robot becoming very poorly utilised. The need to procure new tools also makes it hard to commission the use of the robot quick enough for two of the companies.

Literature and an expert agrees that smaller companies often are too restricted in their resources to act on opportunities.

SMEs often do not have enough competence to make accurate calculations on the profitability of flexible automation according to literature and an expert. This can make them reluctant or restrictive in their investment towards automation.

7.4 Competence

Two experts believe SMEs often do not have enough competence to start their automation journey. Companies are unaware of their need and how to start pursuing the necessary knowledge. It is also very hard for them to determine which supplier to turn towards and to ensure that their lack of knowledge does not get exploited and they buy more complex solution than is necessary.

One expert also believes there is a knowledge gap between the suppliers and user, where the supplier has great technical knowledge but not enough application knowledge, while the user generally have the application knowledge but poor technical competence. Many companies have problems bridging these competences to create an efficient system. Literature and an expert also believes that in many cases the users do not have enough application knowledge at hand to supply the supplier with what they need. The expert suggest that they often needs to make a pre-study and gain basic automation knowledge to effectively work with the supplier.

It is generally not possible for the supplier to take the responsibility of bridging the knowledge.

Two experts showed concern regarding how companies gain the necessary competence. One expert claims that companies often buy automation technology and experiment with it, but this can be resource demanding and the user might get caught between not gaining competence because the automation technology is not used enough and the automation technology not being used enough because they do not have competence. According to the second expert, his customers often do not know how to gain competence and it is up to his company to guide them in how to gain it.

SMEs often have very constrained resources and are often unable to hire people dedicated towards a special function such as automation or robotics, according to both experts and literature. This is also shown true in at least two of the case companies which are unable to support dedicated personnel towards their (flexible) automation. As a result they often have to rely on external competence which might bring other problems.

One expert and literature believes there is often a lack of higher level production knowledge in smaller enterprises. The problem makes it hard for the companies to formalise their requirements, and according to literature they often have problems with sharing their competence within the company.

7.5 Technical

All experts and literature agrees that there are problems when trying to integrate older machinery with the automation technology. It is often hard to create safe communication and is in some cases not even something an integrator will be able to do. Literature believes there is a lot of old equipment in SMEs where they do not have the resources to replace them.

Literature and an expert describes a problem with poor or no integration towards other production and planning programs such as ERP programmes. This problem was also evident during the case company visit where there was no integration between the robot cell and any form of planning program.

Two of the case companies were concerned over the the lack of flexible tooling which could be used for many different product types. One had tested adjustable tooling but believed the changeover time became too big when adjusting the tool.

8 Discussion

In the following chapter the most significant problems will be discussed, how to use the information, followed by discussion about factors which could reduce the validity of the data, ending with a discussion of future work.

8.1 Most significant problems

There are problems with determining what the most significant problems are as all of the data collection was done in a semi-structured manner. There is very little quantified data in the project and there is no way to objectively determine if one problem is more significant than the other. Comparing how often a problem is mentioned was also deemed unfruitful due to the semi-structured nature of the interviews. Just because a problem is not mentioned does not mean it is not something they believe to be a problem. There is also the problem with us somewhat leading the conversation, for example when giving examples of technical problems we often mentioned signal exchange problems especially with old machines. This is something seemingly all expert believed to be a problem, however this does not necessarily indicate how significant the problem is even though they can all recognise it. The determination of what the most significant problems are, is therefore highly subjective as it is simply the opinion of the authors, which they base on their previous knowledge as soon to be production engineers, their expectations of the problem's consequences and how common they perceive the problem to be.

The probably biggest problem is the market trend towards more variation and smaller batches. This is what creates the need for flexibility, as smaller batches means that the changeover need to be faster and more efficient, and the higher variation creates the need for adjustment of the production system towards more different products. This problem is why flexible automation is becoming more relevant. Unfortunately companies are probably unable to do anything against this problem. If they choose to not follow the trend they will likely loose to competitors who are willing to follow the will of the market.

The lack of initial competence was something we perceived as a very common problem which can have significant consequences. Automation technology is generally an expensive investment, it is therefore very important that the investment is put to use. Machines are inherently very stupid and will not be able to complete many tasks which are simple for a human, therefore special consideration is needed to make it efficient. If the company does not actually understand how and when to use it, the automation technology will often become underutilised and will not generate a profit. The lack of competence will also make it very hard to know what to expect. They probably will not be aware of the cost of constantly adjusting the equipment for new product types, or be able to make accurate calculations on the investment. There is also a possibility of the opposite problem where companies do not believe that automation is relevant for them and that it can not create profitability in their company, making them loose out on opportunities. There is also a chance that companies become reluctant towards investing in automation if they have failed previous attempts. This will become detrimental to companies as some degree of automation is clearly the future of production as human labour becomes more expensive and robots become cheaper and more competent. If companies are unwilling to follow the trend, they are not unlikely to loose to competition in the future. These multitude of reasons are why the initial automation competence is a very important problem.

Another significant problem in competence is how to get the necessary level of competence. As many smaller enterprises are unable to have dedicated personnel towards a special function such as automation, they will not be able to have a higher level of competence in this area. They will most likely have to educate existing personnel in the area in order to at least have some competence. It is however hard to create this competence, a common way seem to be experimentation with the equipment at a small scale. This method seem unreliable as there is no guarantee that they will gain a competence from the experimentation that can be used in normal full speed production. As a result the companies will probably be very reliant on external parties for competence whether that be consultants or the suppliers. This might hinder their own development if problems are always fixed by outside parties, there will also be a low flexibility if the company is unable to reconfigure their automation technology to handle new products. We believe competence is necessary to a higher degree when trying to achieve flexible automation which needs both higher process and product flexibility, compared to traditional automation technology which will do the same task over and over again.

This problem might be biased as we are soon to be production engineers, but the companies' poor awareness of their own production is a serious problem. In the context of automation it makes it very hard to determine how the investment would change the capability of the system if the capability is not quantified. This creates a large uncertainty regarding the profitability of automation. It is also very important to have the information formalised, it seems to be common that companies have somewhat awareness of the production but it is not formalised but reside within the experience of the people in the company. A problem is then when that knowledge is needed by others as it will not always be understandable and there will be a lot more work for the other persons trying to interpret the knowledge. The problem becomes especially significant when working with external parties such as a supplier who has a large responsibility in the installation of automation technology. If the information is not formalised there is a chance of misinterpretation where the supplier will not design the automation system the company wants or needs. There is also a big problem if the unawareness of the production system is big enough that they can not answer the questions of the supplier. They would then most likely need to make a costly pre-study of the production system before even determining if they are suitable for automation. Beyond automation, awareness of the production system is important for general improvement work. To improve the process they need to have data to determine what the problems are which becomes very subjective if there is poor information about the processes. It is also very important to quantify what the improvement will bring in order to know if the change is profitable and to then follow up how profitable it was.

One expert mentioned problems with upscaling, however as there is only one source reporting these problems we are hesitant to call them significant. If these problems are common in industry they would be very significant as they would have a big impact. The case companies have not seemed to be able to upscale the automation and the experts generally talk about the initial phase of automation, both might indicate that the upscaling problems are common. If SMEs are unable to go beyond the testing stage of automation technology they will not be able to have an efficient automated production and, might have wasted money and resources on trying to automate and gaining competence but will not be able to make use of the competence. This creates a problem in that the level of automation will stay low and the companies will become less competitive as they can not beat the low cost labour of developing countries.

A great concern for the case companies is the lack of tooling, and this is what two of them found to be the biggest barrier which keeps them from utilising the robot. From literature and experts this seem to be a widespread problem and one which can become very expensive for companies. Product flexibility will mean that there will be a need for a lot of different tools, the difference can sometimes be minuscule but will result in different products being compatible with the tool. To solve this problem there are at least two approaches; get a lot of different tools or get adjustable tools. Getting a lot of tools comes with problems in cost and probably storage and access to the tools. If there is supposed to be automatic change of tool then there will be a significant constraint in how many tools the robot can reach. There are other problems with the adjustable tool, from one of the case companies experience the adjustment for different products take too long. The changeover time becomes big which will force the batches to be bigger which might make them unprofitable. It is hard for companies to determine how to approach this in a fiscally responsible manner. It becomes even harder if the company is a subcontractor without the possibility to decide how future products will be designed, which means they will not be able to plan the robot tools for future products. If the companies are not able to handle the problem they will be inflexible and might fall into the same situation as one of the case companies where their robot is used for about two days per month.

The case companies exhibits large issues with programming. However they all use the same programming interface from the same supplier which might mean the problems they experience are the problems of that software and not programming in general. The software is aimed at lowering the amount of programming expertise needed making it usable by operators instead of robot programmers. The experienced problems are that the simplified interface reduces flexibility and ability to customise the programs. This makes the programs unoptimised and lowers their functionality. However whether this phenomenon is a general result problem for simplified programming interfaces remains unclear. The literature also describes problem with low flexibility in current programming methods for robots and in order to have efficient flexible automation technology we believe it is vital to have programming which is easily adjusted to suit new products that can be done without taking a lot of resource but without sacrificing ability.

Cost is of course always a big barrier, it is generally understood in industry that automation comes with a big initial investment which is a barrier for SMEs. With flexible automation there are even more costs during the life of the automation technology as they will need customisation in order to adjust it for the customer's need. This will make the robot less able to live up to the common perception that they cost a lot during investment but are very cheap during operation. This makes the investment harder and even riskier than traditional automation technology.

Several interviewees describe difficulties in integrating automation with other machines, especially older ones. This problem could be further amplified since SMEs often do not have the resources to replace old machinery. The problem is significant as it seems to be common and can have a hazardous effect on the safety of the robot. If the robot and the machine are not able to communicate quickly and consistently there is a high risk of failure in the production, in best case the failure will lead to a stop in production but it could also lead to injury of people and equipment. Integration towards planning systems also seem to be a problem, according to experts and literature . During our case visit there were no integration with planning programs from the robot. This will force a lot more interaction from the operator where the automation technology is controlled by humans rather than being controlled by other automation technology. This becomes especially problematic as industry is moving towards the concept of industry 4.0 where everything is connected. If they are unable to properly connect their robot and machines they are likely to lose out on a lot of the potential one would gain from automating.

8.2 Comparing data from different sources

The variety of backgrounds of the sources produces equally varied perspectives on the issues facing flexible automation. The case companies often had a technical and economical perspective whereas the experts and literature brought different angles depending on their background. For instance the robot integrator with background in robot installation came from a perspective of competence while the expert involved in automation as a service saw problems with the way companies buy and use robots. This is natural and expected and the large challenge is discerning what the real issues are and most of all which ones are the most important. It provides repetition of the lesson that there are no easy fixes or solutions in any systems where humans are involved.

None of the case companies had fully implemented flexible automation in their system nor did any of them use it on a very frequent basis. This means they still faced hurdles expected in the beginning of their automation project. If companies with a higher degree of automation, preferably flexible automation, were interviewed there would probably have been more focus on problems with optimisation and maintenance of an efficient system as opposed to investment and installation related issues. These problems continue with the experts where there is lack of experts involved directly in operations. The same artificial focus on installation and investment therefore persists throughout. However this is not to say these issues are not important, only that there is a risk other issues that are also important have not risen to the surface.

8.3 Geographical factors

There is a lack of research on flexible automation for SMEs which resulted in the authors using sources which describes problem from other parts of the world. In some cases the findings from the literature will perhaps not be applicable in Sweden. For example the problem with a lack of experts in the industry will probably be less severe in Sweden compared to Poland where experts are emigrating to other countries. The problems from China might also not apply in Sweden as the general level of education is higher in Sweden which might result in the problem of low engineering knowledge not being applicable or at least not as applicable. The cost of human labour will also differ between different parts of the world and might change the perception of what the problems are and what should be achieved with the automation. In China for example automation might be implemented to increase quality and capacity while in Sweden the focus might be on lowering production costs. From our research there is a limited amount of research focused on flexible automation in SMEs and there is even less research on flexible automation in Swedish SMEs. Therefore any source which focused on this topic was used regardless of location of the study.

8.4 Suggestions for future research

We hope that this study has been able to determine what the general problems are but more work needs to be done into quantifying what are the most significant problems. To do this the problems from this thesis could sent as a survey in mass to different experts and SMEs, where they get to rank the significance of the different problem. From the data one would then hopefully be able to more objectively determine which problems are the most important.

We would also have wanted to talk with more people especially companies using automation and have gotten further in their automation journey. We believe they might have a different perspective on the problems compared to companies who have just started automating. It would also have been beneficial if there was more of a dialogue with the interviewees where there are more follow up interviews. Unfortunately time was very limited as the direction of the thesis was almost completely changed half way through. And most of the interviewees for the new subject was available after about a month from the change of direction.

8.5 Social sustainability

Automation can come with the benefit of increased ergonomics as it is often the more repetitive, heavy tasks which gets automated. This should create a lower strain on the workers bodies and companies will as a result have fewer work related injuries increasing the sustainability of the workplace.

There is somewhat of a concern with the robots stealing jobs, which in some ways can be true. Automation is doing tasks which was previously done by a human in many cases, however automation is also creating jobs. There is a need for robot operators, robot installers, robot producers etc. Companies will often be able to produce more, which creates more work for the people downstream. There is also the question of who would loose the job, on the local perspective in high wage countries automation can save jobs. If production is too expensive it can in many cases be outsourced to other countries resulting in a big loss of jobs. With automation the production can become cheaper and the outsourcing can be avoided.

8.6 Environmental sustainability

The ecological sustainability is unlikely to be affected by this thesis. It could in some ways be worse for the environment as more equipment is generally needed for automation compared to manual labour. It also allows for cheaper production which in turn allows for cheaper consumption which could have an environmental impact. It could become more viable to produce locally with increased automation, especially in countries with expensive human labour. As a result there could be less shipping if for example a product which is consumed in Sweden is also produced in Sweden, compared to it being produced in China.

9 Recommendations

Based on a selection of problems several recommendations are given which if applied could help the companies mitigate the effects of the problems.

9.1 The changeover reduction

To achieve higher process flexibility the changeover time always needs to be reduced, as it allows for smaller batches. We therefore believe changeover reduction should be done in any company which wishes to achieve process flexibility. We recommend using the ESEE method described in theory in order to determine how companies can reduce their changeover time.

9.2 Learning organisation

To help remedy the problems of low competence in automation and production, it can be beneficial to try to change the company into more of a learning organisation which supports gaining new competence. We therefore recommend companies to try and follow the steps towards creating a learning organisation, described in the theory chapter. This recommendation will not aim at increasing specific competences but rather guide the companies in a general way of how the organisation should be in order to support learning.

9.3 Gaining initial competence

Gaining the initial competence was deemed to be a significant problem for many companies the authors would be remiss if they did not mention the resources and tools that exist today. The Swedish Agency for Economic and Regional Growth are working on a project called "Robotlyftet" [52], which translates to "The robot lift", in order to help Swedish companies achieve a higher degree of automation they offer a free consultation. The consultation will be in the form of a prerequisite investigation, where they will help the company [52]:

- Review current state and goals of the company
- Line-walk where they review the production in order to understand it and to determine what is a candidate for automation
- Revisit with review of mapping and a joint analysis of the automation possibilities and how the efforts should be prioritised.

The investigation should help the company take their first step towards automating their processes and help them gain the often lacking initial competence which is important when investing in automation technology. The prerequisite investigation also serves as a basis if the company wants to apply for an automation grant by the ministry of growth. The grant will the subsidise the cost of using external parties to increase the competence in automation, the funding is for up to 75% of the project cost and up to 150 000 kr.

To further help Swedish manufacturing companies succeed, Swedprod offers a guide for developing flexible automation in low volume production[53]. The guide includes description of automation principles, methodology for preparing for and choosing automation and general knowledge about automation production[53]. This guide is focused on the practical implementation of automation and is thus different from the recommendations and results of this thesis. The guide takes puts additional focus on factors such as the product catalogue of the user, the production environment, safety, ergonomics, and investment calculations.

10 Conclusion

In order for SMEs to more effectively compete in a market that is going towards mass customisation with short lead times and quick changes to products, there is a need to increase the flexible automation. From the investigation it is clear that a lot of the major problems are in the beginning of the automation journey and the SMEs need a way to gain competence in order to make more effective long term plans with their automaton. Technology needs to catch up in areas like fast and easy programming, robot tools that support flexibility and integration with other machines. If SMEs do not manage to change how they implement and operate automation technology there is a real chance that they will loose their business to countries with cheaper human labour.

To summarise and tie back to the research questions we would like to repeat how they were all answered. The answer to the first question was a list of common problems with flexible automation in SMEs. These problems came in the categories of market, strategy, economical, competence, technical and research. The second question was answered by filtering them down to ten problems while the answer to the last research question was three recommendations on how to mitigate some of them.

However the future does not have to be that grim. We recommend company stakeholders to take part of our list of identified problems to enhance awareness. When companies become aware in which ways they need to improve, the path forward is at least known. We also recommend companies to consider implementing what they need from our recommendations which includes concrete resources they can turn to beyond the theoretical perspectives described. Further we recommend our successors in academia use the identified problems as a road map to what areas need further investigating.

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