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Guide for Automation of Low Volume Production

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Abstract. There is a remaining need from both academia and practitioners, to gain further knowledge about the decision making process for automation of low volume production. This paper includes insights of drivers for automation, the development of a guide for low volume production and the outcome of using the guide. The research in this study is based on both empirical data and theoretical considerations. The empirical data was collected in five case studies and a questionnaire. This paper is part of a research project with the main objective to develop knowledge about how flexible automation may contribute to improvements in efficiency, ergonomics, quality and production economics in different industries with low volume production. One of the results in the project was a comprehensive guide, developed, refined and improved in an iterative collaborative process, where tools and parts of the guide were tested and verified by five manufacturing case companies. The paper describes briefly the development process of the guide and content. The requirements of the guide derived from literature, case companies, questionnaire as well as industrial experts. The resulting guide can be used in several ways, depending on the requirements of the application. The guide includes guiding principles, a decision model for the analysis of the company, choice of automation and facts about automation. In the end of the project, four companies had invested or decided to invest in different types of automation.

Keywords: Flexible automation, decision model, automation investment

Introduction

Customers' demand for variety in products leads to needs for production with lower volumes and higher mix of products. At the same time does automation play a vital role in modern manufacturing, as the main incentives to automate manufacturing is to improve productivity, improve quality and reduce cost as well as get rid of monotonous working tasks [1]. However, for manufacturing companies with low volume production it may be a risk to invest in complex automation technology suitable in the production today, as they continuously introduce and produce new products. Even though the incentives of automation are well-known by practitioners and researchers [1,2,3], many of the manufacturing companies with low volume production, do not believe it is possible to automate low volume production or that an automation investment can pay off. As the

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development of automation technology is fast, there now exist automation technologies suitable for low volume production [4] and this opens up for new automation investments in companies that traditionally have not invested in automation.

The decision to invest in automation may imply possibilities or even be crucial to strengthen a company's competitiveness [3,5,6]. Previous research studies show that the automation technology investments are not always successful [2,6,7]. Automation technology investments can fail due to lack of realistic or defined objectives and structured plans [6,8]. There exists a vast array of literature on decision models for advanced manufacturing technologies including automation technologies [see for example 9,10,11], but the majority of the decision models are conceptual and not tested empirically. The existing empirically tested models either focus on qualitative analysis [see for example 12,13] or quantitative analysis of economy [11]. Only few of them take an overall production system perspective [13]. Moreover, there is a lack of methods and guidance for automation investment for low volume production. Therefore, there is a remaining need to develop a guide for automation of low volume focusing on quantitative analysis of the total economy, supplemented with more qualitative analysis of consequences for the entire production system. The purpose of the paper is to present a guide for automation of low volume production. The paper includes reflections of the development of the guide and the outcome of using the guide.

1. Theoretical considerations

1.1. Decision models for Automation Investments

There exist numerous decision models for advanced manufacturing technologies including automation technology [see for example 14]. Many of these decision models focus on technology selection and justification and they are commonly classified as strategic, economic, analytical or hybrid models [8]. The strategic models are often based on qualitative analysis while the economic and analytical models are based on quantitative analysis. Most of the models are conceptual. These hybrid models often focus on strategic and economic analysis [8, 10, 15]. There is also limited empirical evidence to support whether they are actually used by practitioners [11] and their usability has not been analysed. One empirically tested model for automation decision is the "Lean Automation Handbook" [13]. The handbook is extensively tested in companies and includes several qualitative analyses. Another method, extensively tested at companies, is the evaluation of automation level model including qualitative analysis of suitable level of automation [12].

1.2. Production Economics and Productivity

One of the main incentives for automation is cost reduction [1]. When investing in automation, focus has often been on reduction of personnel. However, to understand the cost of automation in a production system perspective, a broader view is needed. Windmark and Andersson [16] developed a cost model with a broader perspective, including more aspects than just personnel costs. There exist also other methods including both productivity and cost for production system such as the capacity frontiers framework [17] and Productivity Potential Assessment [18].

1.3. Production Ergonomics

Another incentive for automation is to improve ergonomics and eliminate or reduce monotonous jobs. The introduction of new technology and automation affects employees' working conditions, both physically and mentally. The working tasks are changed, new demands arise and new skills are demanded. Here appear both opportunities and risks regarding ergonomics. For ergonomic improvements and to survive and become lasting, integration into production systems and regular development is required, where the results are managed and integrated by already existing working groups [19]. If ergonomics is not integrated, the improvements will not be sustainable over time, and will be reversed in other changes in the production system [20].

2. Research Methodology

This paper reports from a project on flexible automation for low volume production. The main objective was to develop knowledge about how flexible automation may contribute to improvements in efficiency, work organization, ergonomics, quality and production economics in different industries. Based on the findings, a comprehensive guide was developed, briefly presented in this paper.

The research in this study is based on both empirical data and theoretical considerations. The empirical results is based on five case studies and a questionnaire. The case studies were carried out in five manufacturing companies: A, B, C, D and E in 1,5 years period. The case companies represented different industries with varying ownership and size. However, they all considered themselves as having low volume production and wanted to gain more knowledge about automation appropriate for their production. Several of the companies also had high mix of products. Low volume production is often associated with smaller manufacturing companies, but in this study also a larger company in process industry participated. According to [1] low volume is usually described as 1 to 100 units each year. However, low volume production was defined differently by the participating companies, and depend on the products manufactured in the company. In one case company, one product was the usual size of a batch, while in the larger process company, several thousand was the norm for low volume production.

The data collection at the companies included interviews, observations, work sampling studies and tests of parts of the guide, see Table 1. Initially, one strategic interview and one observation were made at each companies, in total five initial interviews and five initial observations. An interview guide was developed and used for in depth interviews with decision makers. The interviews lasted between 60 minutes to 120 minutes. In three cases the interview was a group interview, including two to three decision makers such as owner/CEO, production manager, sales manager, technical manager. The themes for interviews were: description of the company, customers today and tomorrow – what products they buy, production process and material flows, production steps, work tasks and automation level, organization of work, competence, safety, occupational health and sick-leave. The questions were asked in order to clarify and define the companies' development needs, demands for automation and their next step in the automation decision. Observations in manufacturing were conducted to get a deeper understanding of both the production system and specific parts in the production. Work sampling studies were used to identify total work time used for specific activities

in the production. The specific activities were manual activities with potential to be automated. Work sampling studies were made once or twice at all the case companies and they lasted 2 to 6 hours. During the study, informal follow-up meetings and interviews were made continuously with the decision makers. The data collected were documented and analysed and the findings were used to develop and refine the guide.

Table 1. Data collection techniques in the case companies

Activity \ Company	A	B	C	D	E
Strategic interviews	Yes	Yes	Yes	Yes	Yes
Observations	Yes	Yes	Yes	Yes	Yes
Work sampling studies (productivity)	Yes 6h at one automation candidate	Yes 4 h at manual processes at a work stations with flexible automation	Yes 6 h at two automation candidates	Yes At two work stations. 4 h at one and 1 h at the other	Yes 6 h at potential automation candidates
Ergonomic and psychosocial analysis	Yes	Yes		Yes	Yes
Production mapping		Yes	Yes		
Production economic model	Yes	Yes			

To get a broader understanding of reason for automation and driving forces a total of 34 participants from 18 companies other than the case companies responded to a questionnaire on reasons for automation. All participants answered the questionnaire. The questionnaire included eight defined drivers of automation. The drivers were chosen from a mix of experiences, dialogues within the project and literature. The survey was done in parallel with the case studies and the development of the automation guide, at a number of seminars on automation principals and trends. The participating companies in the survey had different numbers of employees, ownership and belonged to different industries etc. They had varied experiences in automation, but all had a genuine interest in production development including automation,

Each informant selected, based on the defined options, the most important driver of automation, the second most important driver and the third most important driver. The results were analysed and concluded. The results of the questionnaire were used to strengthen and verify the design and the contents of the automation guide.

The theoretical considerations in this paper are based on literature reviews and previous experiences of the researchers and authors of this paper. The researchers in this paper have different theoretical backgrounds, and they made their own literature review for their specific area such as production economy and productivity, production ergonomics and materials flow. The theoretical considerations were the base for the development of the guide together with the case companies requirements that were identified in the initial interviews.

The empirical data included the case companies and questionnaire were analysed in an iterative process during the project. For this study, each case was first analysed individually and thereafter there were a cross-case analysis. The findings from each case

and cross-case analysis analysed against the questionnaire and existing literature. The findings constitutes the base for the disscion and conclusion.

3. Drivers for automation

In the interviews at the case companies, ergonomics was mentioned as a main driver by the case companies as automation can do monotonous or heavy working tasks instead of an employee. Other drivers mentioned by the case companies were cost reduction and improved productivity. The companies also described understanding of possibilites for automation and learning about automation as drivers for automation investments.

The results of the questionnarie indicates that the most important main driver of automation was increased productitvy, 20 representatives regarded this as the main driver for automation, see Table 2. Improved ergonomics was ranked as the second most important driver. Cost reduction and improved quality were also prioritized by the companies, but not as the main driver. After these four drivers there was a gap in the ranking, see Table 2.

Table 2. Main drivers of automation. Number of informants: 34. Importance = sum weighted results, most important '3, second most '2, third most '1

Drivers of automation	No 1	No 2	No 3	Sum of all votes	Importance
Increased productivity	20	7	1	28	75
Improved ergonomics	4	10	12	26	44
Cost reduction	4	8	2	14	30
Improved and stable quality	3	4	12	19	29
Improved throughput time	1	2	2	5	9
Hard to find operators	-	1	4	5	6
Tracking possibilities	-	1	1	2	3
Flexibility	2	1	-	3	8
Others	-	-	-	0	0

4. The Automation Guide: Requirements, development and learnings

4.1. Requirements

The requirements of a guide for automation were derived from the theoretical considerations, previous experiences by the research team, representatives from a union and industry associations, an automation solution supplier and the case companies. The guide should:

- Integrate productivity, ergonomics and economics
- Provide companies with self-help, be a guide for automation decision
- Be easy to use for production technicians or production managers in small and medium-sized enterprises (SMEs) with low volume production
- Be based on and stimulate participation
- Include transparency and visualization
- Aim for long term gain and sustainability
- Be built on existing knowledge that can be adapted and adjusted to suit automation decision for low volume production

4.2. Development of a guide for automation

To develop an industrial useable guide, we identified existing decision models and tools for productivity, ergonomics and production economics, as well as overall checklists to understand what models that were most suitable for automation decision for low volume production. For the productivity part, the Potential Productivity Assessment [18], capacity frontiers method was the foundation. Results from Windmark och Andersson [16] were used as foundation for the production economic model. The ergonomic part involved physical exposure and psychological strain. The assessment of physical exposure is a screening, based on recurring factors in several existing methods combined with quantitative values by estimating the proportion of each factor in the tasks. For assessment of psychological strain, parts of the Potential Productivity Assessment [18] were used.

The draft guide was successively developed, adapted and adjusted in an iterative and collaborative process. In this process, the five companies continuously tested different tools and parts of the guide. Representatives from the case companies, research team and an automation solution supplier evaluated the results of the tests, and iteratively refined and improved the tools and different parts of the guide into a final version. The guide was gradually expanded to also include new parts and guiding principles and the three initial parts were intergrated into a decision model. Here, the results of the questionnaire were used to further understand what to be included (or not included) in the guide. The tests and activities undertaken at the five case companies are summarized in Table 1.

5. The Automation Guide: A flexible and pedagogical tool

The automation guide is divided into three sections:

1. Guiding principles for automation
2. Decision model for the analysis of the company and choice of automation
3. Facts about automation and robotics

The guiding principles for automation include:

- Automation as a mean to create both competitiveness as well as more sustainable work stations
- Identify and remove waste before automation
- Put safety first
- Start simple, then increase level of complexity and difficulty
- Maintain the layout as changes can be expensive
- Understanding requirements for handling in the manufacturing process
- Adaptation of the products for automated production

The decision model offers guidance through the automation decision process, beginning with the company on an overall strategy level and alignment of strategy to the automation decision. Thereafter, the decision model is divided into a four step model, see Figure 1, that leads to the automation decision investment. Step 1 includes questions about automation and the company's prerequisites for automation. Step 2 includes a

production mapping to understand the overall system and which work station that is suitable for automation. This work station is analysed further. Analysis in Step 3 includes analysis of the whole workstation, operators activities and ergonomics including work content. Step 4 includes the production economy model, focusing on productivity and effects of the investment. These analyzes and mappings lead to the last step; the decision. Each part also include recommended tools such as deeper production mapping, work sampling studies and ergonomics.

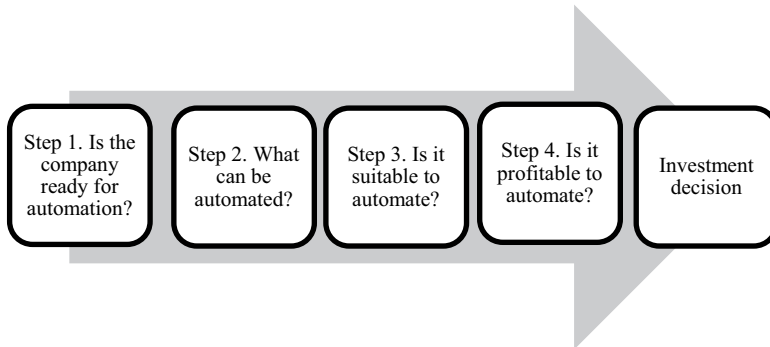


Figure 1. The decision model for automation investment

The complete automation guide is available in Swedish as well as in English. The Swedish version is also available in a web format and can be accessed at www.edig.nu/swedprod.

6. Outcome of using the guide

The empirical outcome of the project was that four of the five case companies had invested or decided to invest in automation.

Company A had invested in flexible and moveable automation solution before the beginning of the project, but the automation solution was implemented during the project. The company did not make any other automation investment decisions during the project.

Company B had invested in flexible and moveable automation solution before the beginning of the project, but the automation solution was implemented during the project. At the same work station as the flexible automation solution, the company invested in an used robot during the project. During the project, they also decided to invest in a robotic cell for another work station. This robotic cell was implemented in 2019, after the project ended.

Company C had several ideas of potential work stations suitable to automate, and one work station was studied further. However, after a production mapping and strategic analysis, the company decided to not automate the work station, but another work station. They also decided to improve the material flows.

Company D wanted to learn about automation and where to use it in manufacturing. The research team studied two different work stations, and one of the work stations was

identified as suitable to automate. They decided to invest in a collaborative robot in this cell during the project.

Company E decided to invest in a robotic cell during the project in order for operators to learn about automation as well as to increase productivity in the work station. The work station was identified by both the research team and company as potential automation candidate. The cell included a machine, a used traditional industrial robot and new material handling equipment. The company acquired a used robot from a company in their company group. Due to delays from the machine supplier considering integration, the robotic cell was not implemented during the project.

7. Discussion

The literature on automation for low volume production and flexibility is very limited, just like literature on automation in SMEs. Low volume production with high variation and flexibility is often related to a low level of automation [see for example 21,22]. The research project focused on the today existing flexible automation for low volume production, the needs in companies and their decision process for automation. Flexible automation is automation technology that can perform a variety of industrial tasks and is not dedicated to one machine or one product and therefore assumed to be more suitable for companies with low volume production. The companies that participated in the project had interest of automation with such flexibility. The findings from this study is that the case companies invested in different types of flexible automation depending on prerequisites and needs based on their low volume production.

A lesson learned from the guide development process, was the significance of the companies readiness for automation. Readiness means to have the right competence and knowledge of automation specifications, investments and implementation on several organisational levels. In the smaller case companies this means that both operator, production manager and chief executive/owner were involved in the automation decision. It is vital that the operators are involved and engaged as early as possible, as they should learn to handle the automation.

The manufacturing steps, including material flows, work stations and all manufacturing operation steps, need to be identified, mapped and analysed in order to understand where and how automation can be used as a value-added activity.

A work station in one company was identified as a candidate for automation. After a work sampling study of this work station was performed, the results showed that the work station was not a candidate, for several reasons such as lack of spare parts and unclear flow. To understand the manufacturing and identify value-added activities, a production mapping was conducted. Literature [22] describe that companies need to eliminate waste before introducing automation. If not, waste, i.e. non-value-added activities, may be automated. Lessons learned from this was to add some principles in the guide, inspired by lean [24], but adapted to support decisions on flexible automation. Such an approach is found in [13], but without focus on flexible automation for low volume.

Automation implies changes in the system and work environment, for example new work tasks for the operator and changed utilization of the equipment. Before investing in automation, these changes need to be considered as they may affect both the overall production system and work tasks for the employees. Therefore, a scenario analysis is

essential, to understand what can be done with the capacity of both employees and equipment and the released working time. Due to this, analyses of several capacity effects are included in the production economic model in the guide.

The different case companies had slightly different requirements of the guide and reasons to automate. Several of the case companies wanted to get rid of monotonous and heavy working tasks. Other reasons for automation was to reduce cost or to get knowledge about automation. This lead to a flexible guide, flexible in terms of that the different parts in the guide could be used separately. Due to this, the guide also includes a user manual and recommendations of existing tools, such as work sampling studies, ergonomic analysis as well as a different way of calculating cost for the investment. Moreover, the needs and reasons for automation in the case companies also affected which part of the guide they tested. This flexibility has not been included in previous automation decision models.

Based on the results of the initial interviews with the case companies, a strategic part was included in the guide. The strategic part evolved during the project, first focusing on manufacturing strategy, and later developed into an overall map on how to align strategy with automation decisions. The strategic part was also used by the research team as a data collection technology to visualise and discuss the development of the each case company. Several of the existing automation decision models include strategic parts [5,6,8,13]. Often, these models focus on quantitative analysis, while the strategic part in this guide focus on how to align strategy with automation. Research has shown that automation decisions, aligned with strategy, tend to be more succesful than automation decisions not aligned [7].

The ergonomic screening template in the guide was appreciated by the companies, especially the relative simplicity of estimating the physical exposure to get an initial screening. The experience is that the screening is illustrative and possible for the companies to do on their own.

The main drivers for automation identified in the questionnaire (Table 2) were increased productivity, ergonomics and cost reduction, and this is verified in literature by for example [1]. A recent global survey about automation conducted with 85 OEMs and described in [2] ranked reduction of cost, improved quality, improved productivity and improved capabilities of robots as the main driver for investment in automation. The difference between the results of this questionnaire in this paper, and the survey in [2] may depend on the number of employees and experience of automation in the companies participating. In [2], the OEMs that participated in the survey were large global companies, while in the questionnaire in this paper, the majority of companies were SMEs in one country. SMEs have not invested in automation to the same extent as larger companies and they have different characteristics and requirements on automation than larger companies. This can be one explanation of why productivity was ranked most important in the questionnaire and not in the global survey described in [2]. The difference is also emphasised in the case study. The case companies had different reasons to automate, and many of them described flexibility and ergonomics as the main drivers for automation. This difference may depend on the selection of case companies in the research project. The case companies wanted to participate in the research project due to their interest in flexible automation for low volume production.

8. Conclusion

Automation for low volume production is gaining more and more interest from both practitioners and academia. To facilitate the automation decision process for companies with low volume production, a guide for automation of low volume was developed. The foundation of the guide was earlier research in different areas such as production economics, productivity and ergonomics and the final version of the guide also includes theories about strategy and materials flow. Previous research has inspired the development and results and experiences in these areas have been adjusted and adapted to suit automation for low volumes. The guide is flexible and separate parts can be used independently. The different parts in the guide also include recommendations of useful tools for deeper studies and understanding.

In general, the main drivers for automation are increased productivity and ergonomics, Table 2. The research project concerns questions about flexibility for low volume and often high mix of products. The design of the guide is based on a generic decision process, how to evaluate and decide for automation, Figure 1.

The main results from the research project are:

- Five companies increased their knowledge on automation for low volume production as a way of improving competitiveness and ergonomics.
- The automation guide was created as a flexible tool for different requirements..
- Four of the case companies invested in or decided to invest in different types of flexible automation depending on their prerequisites and needs based on their product mix and manufacturing volumes.

The guide will in future be further developed, including more tools useful for specific low volume high mix manufacturing, in a continuation project. Two of the case companies will participate as well as three new companies from different sectors and with different number of employees.

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