Evaluation of flexible automation for small batch production

Citation for the original published paper (version of record):
Löfving, M., Almström, P., Jarebrant, C. et al (2018). Evaluation of flexible automation for small batch production. Procedia Manufacturing, 25: 177-184.
http://dx.doi.org/10.1016/j.promfg.2018.06.072

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 25 (2018) 177–184

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

8th Swedish Production Symposium, SPS 2018, 16-18 May 2018, Stockholm, Sweden

Evaluation of flexible automation for small batch production

Malin Löfving[a,b,*], Peter Almström[b], Caroline Jarebrant[c], Boel Wadman[c], Magnus Widfeldt[c]

[a]Träcentrum Nässjö Kompetensutveckling AB, Box 174, 571 22 Nässjö, Sweden,
[b]Chalmers University of Technology, 412 96 Gothenburg, Sweden
[c]Swerea IVF, Box 104, 431 22 Mölndal, Sweden

Abstract

Traditionally it has been difficult to use automation in small batch production with high variation in volumes and high mix of products. However, this is changing as there exist new types of flexible automation. The purpose of this paper is to understand the requirements on enterprises to use automation in small batch production, and evaluate flexible automation technologies suitable for small batch production. The study is based on literature reviews and interviews. Identified requirements are for example to change between manual access and automation, and easy programming. The results show that a flexible mobile robot automation may fulfill a majority of the identified requirements.

Peer-review under responsibility of the scientific committee of the 8th Swedish Production Symposium.

Keywords: Small batch production, mobile automation

1. Introduction

A majority of the manufacturing industry consists of small and medium-sized companies working exclusively with small batch production. The variation in volumes and components leads to an uneven and low utilization of machines and low effectiveness of the working force. These companies are also labor intensive as machines are often operated

* Corresponding author. Tel.: +46-380-554320
E-mail address: malin@tracentrum.se

2351-9789
Peer-review under responsibility of the scientific committee of the 8th Swedish Production Symposium.
10.1016/j.promfg.2018.06.072

manually [1]. Manual tasks in manufacturing operations are for example machine loading and unloading, part inspection, and bin picking. Moreover, in small batch production in Sweden, the degree of automation in manufacturing operation is extremely low, under 1%. One reason for this is that traditionally, industrial fixed automation was developed for high-volume, low variety production [1,2,3]. The traditional industrial automation concepts are not considered useful in small batch production due to their cost of implementation, long duration of programming, inflexibility, dedication, safety concerns and fixed position [1,4,5]. Lately, new types of flexible automation has been developed that may be suitable for small batch production. There is a great potential for small batch producers to use flexible automation in manufacturing operation to remain competitive. However, this requires knowledge of the requirements among small batch producers concerning the flexible automation to be useful. Research studies focusing on automation for manufacturing operation for small batch production are limited and there are even fewer studies on flexible automation for small batch production. This paper is a first step to understand the potential of new flexible automation for small batch production. The purpose of this paper is to understand the requirements on automation in small batch production, and evaluate flexible automation technologies suitable for small batch production.

2. Theoretical background

Traditionally flexible automation refers to a computerized manufacturing system involving CAD, CAM, an automatic storage, retrieval system (AS/RS) and computers that integrates these (see for example [5]). According to [7] (p.444)"*Flexible automation allows rapid reconfigurability of the production system in order to manufacture several different products, achieving high degree of machine utilisation, reduction of in-process inventory, as well as decrease in response times to meet the changing customer preferences."* There are numerous articles about flexible automation focusing on the FMS with fixed robots and articles about flexibility in manufacturing, all of them aiming at the whole manufacturing system. In this paper, the flexible automation is delimited to an automation technology. Flexible automation in this paper refers to a moveable robot with integrated technologies which are able to adapt to changing environment and perform a variety of industrial tasks, i.e. not dedicated. One advantage with moveable robots is the possibility to be used for different machines and applications, i.e. they can be moved to the position where they are needed. Flexible automation is the ability for a robot to be quickly and easily re-tasked to change products and volumes. Three different categories of flexible automation were derived from the literature review; collaborative robots, autonomous automation and mobile automation.

- Collaborative robots. Traditional industrial fixed robots are described as unsafe for human worker and therefore caged off from human workers, often with fences (see eg. [8,9]). Recent advances in automation technologies have enabled new types of robots that are safe for human workers and that can be integrated into human-robot working cells [8,9]. There are papers describing specific collaborative robots such as Yumi and Baxter and their potential [8,9,10]). Papers also describe the human-robot collaboration, e.g. how humans and robots can collaborate to assemble components [1,8].

  Both traditional industrial robots as well as collaborative robots can be mobile. Two kinds two kinds of mobile automation; autonomous automation or mobile automation that are moved manually were identified in the literature review.
- Autonomous automation. [4] describe that automatic mobile robots extends the prospective application of industrial fixed robots by combing locomotion capabilities with manipulation abilities. Moreover, mobile robots' interaction and communication capabilities have according to [4] reached a point where they can be integrated into the manufacturing network. Automatic integrated with AGV technology or can be moved with help of an AGV [11].
- Mobile automation. Another option to move the robot is to carry it or move it manually with a fork e.g. a lift. Both autonomous automation and mobile automation can be found in previous R&D projects and in industrial applications. A huge installation with movable and offline-programmed robots for arc welding automation, were introduced in late 1980s in the Odense Steel Shipyard [12]. In the project "Factory in a box", five industrial demonstrators were made, were flexible robot automation could be moved to e.g. different factories [13]. A late example of a "robot on demand" was presented by Fraunhofer IFAM [14]

3. Method

This paper reports the first results of a research project financed by The Swedish Governmental Agency for Innovation Systems (VINNOVA) 2016-2018. The project will use pilot studies to demonstrate if it is possible to create both profitable, competitive and sustainable small batch production as well as flexible high volume production. One objective of the project is to develop knowledge about how flexible automation can contribute to improvements in work organization, ergonomics, quality and production economics in different industries by developing guidelines for the automation investment.

The results presented in this paper follow a four-stage logic. Firstly, a literature review was conducted identifying categories of flexible automation technologies. Secondly, requirements on automation were established from case studies. Thirdly, identified flexible automation technologies were evaluated against the empirical requirements. Finally, when a automation technology was identified as fulfilling most of the empirical requirements, a specific analysis of that technology was done.

During the first stage, the literature review, a number of databases were selected to cover a diverse range of publications (journal articles, conference papers, books, dissertations and thesis). The databases include Scopus, Science Direct. Keywords included flexible automation OR robot, collaborative robots, mobile automation OR robot, moveable automation OR robot. Finally, three categories of flexible automation were identified. Based on these, robot solutions from different companies were identified and studied further to understand the different categories of flexible automation. In total 15 different flexible automation solutions were identified and categorized based on the three categories introduced in the theory chapter.

In the second stage, requirements on flexible automation in small batch production were identified through three single-case studies. The case studies represent three manufacturing companies, labelled Case Sheet, Case Metal and Case Wood. The case companies were selected Data were collected by means of interviews, individually and in group, seminars and observations at each company. The case companies also attended project meetings. Interviews were carried out with the CEO of the company. In two of the companies group interviews were conducted with CEO and production manager or production technician. Observations were made at several times in the studied production process and during these observations, informal interviews with operators, production technicians and production managers were performed. The observations lasted between 30 minutes and 5 hours. In the project so far there has been one project meeting with the project partners attending. The project meeting lasted 5 hours. The respondents were asked about requirements on automation in small batch production. Based on this, requirements on automation were identified.

During the third stage of the research, the analysis to identify suitable flexible automation for small batch production was conducted. When the 15 automation technologies were analyzed it became evident that there existed similarities between certain automation technologies and therefore subcategories of each category was developed. The subcategories are hereafter called small automation and large automation. Small automation means automation with weight under 100 kg and payload less than 15 kg. Each automation technology was analyzed and evaluated based on the empirical requirements, described in the next chapter. When a category fulfilled a requirement, it was marked with "yes". This paper only show the summary of each category's automation technology as this part of the paper aims to identify suitable categories of flexible automation for manufacturing in small batch production, not describing a preferable brand.

Below is a short description of each case company.

- Company Sheet is a sheet metal subcontractor for customers in different industrial sectors. Company Sheet focuses on selling complete solutions to the customers. The company manufacture over 9000 components in different volumes. Competitive priorities are quality, delivery time, flexibility and services. They have under 50 employees. The owners have a long term plan including automation strategies. The company has invested in both fixed robots for material handling, automated machines and a new type of flexible and moveable automation technology for material handling.
- Company Metal is also a sheet metal subcontractor selling complete solutions to customers in different industries and have under 50 employees. Competitive priorities are quality, delivery time, flexibility and services. They are process oriented and offer the newest technology to the customers. The company have invested in several automation solutions the recent years, both fixed and flexible automation technologies for different purposes.
- Company Wood is a company in the wood products industry and is mostly subcontractors to other companies in

the wood product industry. They have under 50 employees. Competitive priorities are quality, flexibility. They have a long term plan including automation strategies and they have invested in fixed automation technologies.

4. Requirements of flexible automation in practice

Below is a description of the requirements identified from the empirical data.

4.1 Material handling

When asking the respondents in the case companies about their requirements on flexible automation, they all talked about automation technologies serving machines, i.e. material handling in and out of machines in manufacturing. Two of the case companies also require higher productivity when invest in automation. One way to increase productivity according to the case companies is to let the automation serve machines during the evening or night shift. Therefore another requirement is that the automation should be able to serve machines during one shift without manual support.

4.2 *Easy programming for operators*

All respondents in the case companies mentioned that the programming of the automation technology needs to be simple and time-efficient. Case Sheet and Case Metal had experiences of fixed automation technology in the form of fixed robots that served a machine. In one of the companies the fixed robots were not used much, as according to both CEO and machine operators it took several hours to program it. According to the respondents in this case it took shorter time to manually serve the machine per order than to program the robot and let the robot serve the machine. As the case companies have many components in smaller volumes, they sometimes need to reprogram machines and automation several times a day, and therefore they require short reprogramming times for the flexible automation. With time-efficient reprogramming they mean a couple of minutes. Another requirement was that the operators should be able to program new components as well as do the reprogramming. This required according to the companies simple interface and simple programming.

The companies also required simple and time-efficient installation of the automation. The installation also include education of the operators who are going to support the automation.

4.3 *Mobility*

The three case companies had batch production layout with different departments and dedicated machines to one process, for example sheet metal bending. This meant that the machines were sometimes located quite far from each other. The companies wanted an automation suitable for this kind of layout and did not want to move machines to enable robot cells. A requirement was that the automation technology should be moveable so it could server several machines in one department. The companies had several machines with the same purposes in the plant and the availability of the machines in one department was order dependent. To serve the “right” machine, they wanted to move the flexible automation technology between machines. The movement of the automation technology should also be simple and preferable made manually. Here the repetitiveness and positioning accuracy is essential as the machines often had fixtures with very low tolerances where the components should be positioned.

4.4 *Safety solutions*

All three case companies manufactured several components in different volumes and according to all companies they needed manual access to machines when the manufactured components in low volumes. Company Sheet for example had orders with as few as four components. They said that these orders should be handled manually as it took longer time to reprogram the automation technology than to manually serve the machine. This was also the case for more complex products that needed many different operations in one machine. Therefore the companies required manual access to the machine

The case companies required automation technology with no fences or few fences. The requirement of no fences or few fences derived from the limited amount of free space in the plants as well as from the need to ease manual access to the machines. No fences also made the relocation of the automation technology easier.

4.5 *Payload*

The size, dimension, and weight of components that the companies manufactured varied. All three case companies required automation that could lift ungainly, large and/or heavy components. Heavy components are components that weigh more than 10 kg; ungainly components can be round components that cannot be lifted between the arms. Case Wood and Case Sheet had several large dimension of components, where one example was a component that measured 1000x1000 mm, another example was a component that measured 1200x1800 mm.

Table 1 shows the empirically derived requirements on flexible automation for small batch production.

Table 1. Summary of the empirically derived requirements on flexible automation for small batch production

Material handling	**Easy programming for operators**	**Mobility**	**Safety solutions**	**Payload**
Machine tending Working evening and/or nights without manual support	Easy to install Simple interface Simple and time-efficient programming	Move between machines Repetitiveness and positioning accuracy Move manually	No fences Manual access to machines	Ungainly components Large components Heavy components

5. Evaluation of flexible automation technology for small batch production

The result from the evaluation is presented in Table 2. As seen in Table 2, there is a difference between mobile automation and autonomous automation considering the fulfillment of the requirements. The mobile automation has some advantages such as mobility as well as other advantages, as easy programming and payload, while the autonomous automation main advantage seems to be the mobility. The was a lack of information about programming for the autonomous automation concepts and this made it more difficult to evaluate this category. Below is a short presentation of the result for each requirement.

5.1 *Material handling*

The case companies required automation for machine tending and most collaborative robots aims at assembly. Few automation technologies have a description regarding the installation.

5.2 *Easy programming*

The interaction between automation controllers to CADCAM systems capable of offline programming, is generally a way to decrease production down time due to programming. The case companies mentioned that the automation should be easy to program with easy interface and should be easy to learn. A majority of the automation technologies in collaborative robot category as well as in the mobile automation category include some kind of easy programming that is easy to learn. There exist different kinds of quick programming from self-learning robots to app programming and easy interface. Specific information about programming was lacking in the descriptions for autonomous automation concepts.

To enable a higher productivity and efficiency in all the machines, it was essential for the case companies to be able to move the automation between machines, as the layout in the plant was fixed and machines were distributed in the different departments. Most of the technologies in the categories could be moved except the large collaborative robot. The positioning accuracy and repetitiveness of the automation technology were also essential for the manufacturing operation. Here the autonomous technologies had lower positioning accuracy and repetitiveness than the other categories. To the large mobile automation technologies a fixture to position the automation in were offered to secure the repetitiveness and positioning accuracy and enable easier movement of the automation.

5.4 Safety solutions

The case companies required manual access to machines without fences and all technologies fulfilled this requirement.

Table 2. Evaluation of flexible automation technologies against empirical requirements

	Collaborative robot		**Autonomous automation**		**Mobile automation**	
	Small	**Large**	**Small**	**Large**	**Small**	**Large**
Material handling						
Machine tending	Most assembly	Yes	Yes	Yes	Yes	Yes
Working night or evening shift without manual support	Yes	Yes	No	No	Yes	Yes
Easy progamming for operators						
Easy to install	Yes	Yes	NA	As industrial robots	Yes	Yes
Simple interface	Yes	Yes	NA	As industrial robots	Yes	Yes
Simple and time-efficient programming	Yes	Yes	NA	As industrial robots	Yes	Yes
Mobility						
Move between machines	Yes	No	Yes	Yes	Yes	Yes
Repetitiveness and positioning accuracy	High	High	Lower	Lower	High	High
Move manually	Yes	No	No	No	Yes	Yes
Safety solutions						
No fences	Yes	Yes	Yes	Yes	Yes	Yes
Manual access to machines	Yes	Yes	Yes	Yes	Yes	Yes
Payload						
Ungainly components	No	yes	No	Yes	No	Yes
Large components	No	Yes	No	Yes	No	Yes
Heavy components	Up to 15 kg	Up to 35 kg	Up to12 kg	Yes	No	Yes
Summary:	10/15	11/15	6/15	8/15	11/15	15/15

5.5. *Payload*

The main limitation in this evaluation is the required payload and size of components for the case companies as they manufacture heavy, ungainly and large components. Most of the automation technologies could not lift these kinds of components. Only one collaborative robot had payload over 15 kg. Here they autonomous and mobile automation offered more alternatives as many of these technologies offered traditional industry robots on top of the trolley. In these cases the payload was unlimited for the really large robots.

6. Discussion and conclusion

One interesting findings related to the programming was that the case companies wanted the operators to program the automation instead of production technicians or likewise. This require a simple and time-efficient programming of the automation. One main advantage for the new types of flexible automation is a new type of robot programming, with e.g. preprogrammed operations and new simple interface, that enable operators to program the automation tasks in shorter time and more intuitively than before. The two case companies that had invested in fixed robots said that the robot programming of fixed robots was not time-efficient. Here the flexible automation with easy programming can ease the decision for small batch producers to invest in automation as the easy programming save both time and cost for the company.

The positioning accuracy and repetitiveness essential for machine tending was not as high in the autonomous automation category as in the other categories. The case companies also wanted the robot to work evening and or nightshift. It was unsure if the autonomous automation technologies could work so many hours without charging. Therefore the most suitable flexible automation technology for manufacturing for small batch production considering the case companies requirement may be the large mobile automation technologies that offer easy programming, easy mobility, positioning accuracy with fixtures in front of each machine, high payload without fences.

The requirement that operators should program the automation also affect the operators working tasks and their competence. Before and under installation of the new automation, operators needs to be involved to learn the automation technology and this also mean a new organization of the company. The changed organization and working tasks for operators will be further studied in the project and presented in future research papers.

The category that fulfilled all of the requirements was large mobile automation. The large mobile automation concepts can be moved easily with a fork lift and have other safety solution than fences that enable area effectiveness and manual access to the machine. Collaborative robots focus on the collaboration with humans and many of these technologies implies one or two arms that lift a few kilo per arm as a human. Their main task seems also to be assembly, that were not the main processes for the case companies. If the case companies had required suitable automation for smaller components and assembly, then collaborative robots is a suitable concept for the companies. We have not identified other studies focusing on the new type of mobile automation concepts identified in this paper, and more research needs to be conducted to understand what this means for small batch producers. However as a majority of the companies in Sweden are small batch producers this is a relevant topic so these companies can remain competitive.

This research focused on understanding the requirements on enterprises to use automation in small batch production and evaluate flexible automation technologies suitable for small batch production. This study contain the requirements from three manufacturing companies and the findings cannot be generalized to all manufacturing companies. What flexible automation is most suitable for a company may depend on the specific process or activity that needs to be automated and this can be different in the company as there exist different processes and activities in a company. However, in the three case companies with small batch production and high mix low volumes the requirements were similar event if the companies are from different industries.

Acknowledgements

The authors wish to thank Vinnova, the Swedish Governmental Agency for Innovation Systems for their finacial support. The authors also want to thank the project partners in the project.

References

[1] D. Antonelli, S. Astanin, G. Bruno, in H. Afsarmanesh et al. (Eds.), Applicablity of Human-Robot Collaboration to Small Batch Production, PRO-VE 2016, IFIP AICT 480, Springer International Publishing Switzerland, 2016, pp. 24-32.
[2] M.P. Groover, Automation, production systems, and computer-intergrated manufacturing, Prentice Hall, Upper Saddle River, 2007.
[3] B. Sjøbakk, M.K. Thomassen, E. Alfnes, Implications of automation in engineer-to-order production: a case study. Advances in Manufacturing 2(2), (2014) 141-149.
[4] I. Nielsen, Q.V. Dang, G. Bocewicz, Z. Banaszak, A methodology for implementation of mobile robot in adaptive manufacturing environments. Journal of Intelligent Manufacturing. 28(5) (2017) 1171-1188.
[5] T. Brogårdh, Present and future robot control development—An industrial perspective. Annual Reviews in Control, 31(1), (2007) 69-79.
[6] R. Parthasarthy and S. P. Sethi, Relating strategy and structure to flexible automation: a test of fit and performance implications. *Strategic Management Journal* 14(7) (1993) 529-549.
[7] R. S. Wadhwa, Flexiblity in manufacturing automation: A living lab case study of Norwegian metalcasting SMEs. Journal of Manufacturing Systems, 31 (2012) 444-454.
[8] A. Sauppé and B. Mutlu, The social impact of a robot co-worker in industrial settings. In Proceedings of the 33rd annual ACM conference on human factors in computing systems, (2015).
[9] B. Matthias, S. Kock, H. Jerregard, M. Källman, I. Lundberg, Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept. In Assembly and Manufacturing (ISAM), 2011 IEEE International Symposium on (2011) 1-6).
[10] S. Kock, T. Vittor, B. Matthias, H. Jerregard, M. Källman, I. Lundberg, R. Mellander, M. Hedelind, Robot concept for scalable, flexible assembly automation: A technology study on a harmless dual-armed robot. In Assembly and Manufacturing (ISAM), 2011 IEEE International Symposium (2011) 1-5.
[11] M. Pehrson and D. Sehlin, Integrering av robotar hos Saab Aerostructures, Thesis, Linköping University, 2016.
[12] R. Boekholt, Welding Mechanisation and Automation in Shipbuilding Worldwide: Production Methods and Trends Based on Yard Capacity, Elsevier, (1996) 187-194.
[13] M. Jackson, M. Wiktorsson, M. Bellgran, Factory-in-a-box — Demonstrating the next generation manufacturing provider. In: Mitsuishi M., Ueda K., Kimura F. (eds) Manufacturing Systems and Technologies for the New Frontier. Springer, London, 2008.
[14] Fraunhofer IFAM web information, https://www.ifam.fraunhofer.de/en/Press_Releases/robot_on_demand.html, 2016.