LEAN AUTOMATION: REQUIREMENTS AND SOLUTIONS FOR EFFICIENT USE OF ROBOT AUTOMATION IN THE SWEDISH MANUFACTURING INDUSTRY

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Abstract

Globalization, demographic changes and environmental challenges are putting strong pressure on the European manufacturing industry and increasing demand on resource efficiency, sustainable manufacturing, innovative and individualized products. Today, Swedish manufacturing in mature traditional sectors is increasingly migrating to low-wage countries such as China and India. There is a strong need for the manufacturing industry in Sweden to enhance the ability to develop and manufacture products competitively. One way could be through an increased level of automation and increased use of industrial robotics. However, robot automation investments are in many cases regarded as too expensive and too technically advanced, especially within small and medium-sized enterprises. The objective of this study was to investigate requirements and possible solutions for the efficient use of robot automation in the Swedish manufacturing industry. Results from the two research projects tied to this study are presented here. In the first project, requirements of automation solutions within small and medium-sized manufacturing companies were analyzed. The second project looked at the development of possible solutions for increasing the reconfigurability of robotic systems, thereby enabling production of different products and simple configuration to handle future product variants without large additional investments.

Introduction

Globalization and the increasing challenge from low-wage competitors highlight the need for Swedish manufacturing industries to enhance their ability to develop and manufacture products competitively. This competitive climate is described by ManuFuture, which is a European Technology Platform specifying important development areas for future production systems, called the Strategic Research Agenda [1]. One of their conclusions was the development of future knowledge-based factories which would require research into adaptive structures and solutions that would provide for continuous change. Some examples of such structures and solutions include 1) management models and systems following the objectives of self-organization and self-optimization, 2) reconfigurable technical systems and integrated processes/systems, 3) technical intelligence in process control systems with efficient human-machine interfaces, and 4) efficient networking in systems based on standards and open-system architecture [1].

One way to handle the current manufacturing challenges and improve a company's efficiency could be to invest in automation and industrial robotics. Ever since the first industrial robots were launched to help, mainly in the automotive industry during the early 1960s, the robot has been used to replace humans in work environments unsuitable for humans due to, for example, heavy lifting, monotonous movements or hazardous conditions [2]. Long accepted by industry as a method for improving quality, performance and efficiency, robotics has for at least three decades been a key technology in manufacturing industries [3], where is has been employed in order to increase industrial productivity and competitiveness in manufacturing. Highly automated production systems with a limited amount of manual work will enable countries with high labor costs, like Sweden, to compete globally [4].

However, robot automation is in many cases regarded as too expensive and too technically advanced, especially within small and medium-sized enterprises (SMEs). Research shows that many SMEs have little confidence in their ability to implement changes in the robotic working cells [5]. SMEs also feel uncomfortable having to rely on outside experts in order to handle day-to-day activities such as introducing new products or fixing small problems.

Another question and debate within industry is whether traditional robot automation fits the principles and practices of lean, which many manufacturing companies currently are trying to implement. When conducting interviews in industry, one can receive comments like: "Automation and industrial robotics create complexity" or "Robotics and lean do not fit together; rather, they contradict each other". In some cases, companies have even started to remove automation, motivated with a reference to Toyota as a company that does not use advanced manufacturing technologies. Thus, another challenge is the adaptation of automation to the principles and practices of lean production [5].

Based on the aforementioned challenges, the overall objective of this study was to investigate the requirements and possible solutions for the efficient use of robot automation in the Swedish manufacturing industry. Results from the two research projects tied to this study are presented here and show how industrial automation and robotics can increase manufacturing competitiveness in industry. In the first project, requirements of automation solutions within SMEs are analyzed. The second project looked at possible solutions for increasing the reconfigurability of robotic systems, thereby enabling production of different products and simple configuration to handle future product variants without large additional investments.

Research Method

This paper presents results from two research projects which were based on a case study research methodology, including interviews, direct observations and, to some extent, practical development in industry. A case study is a preferred research strategy when a specific phenomenon is to be closely studied within its natural context [6]. Case studies can be characterized by the fact that they often look at phenomena when and where they occur and that the exact context or delimitations are not fully known [6]. The two research projects included both literature studies of theory related to lean manufacturing and automation, as well as empirical data collection from industry.

During the first research project, an analysis was done on the requirements on automation solutions within small and medium-sized manufacturing companies. The evaluation and analysis was based on 45 case studies, performed at different SMEs in the region of Eskilstuna, Sweden, between the years 2005-2009. These case studies were executed within the manufacturing system with the objective of investigating the possibilities of using robot automation to improve industrial competitiveness. These studies were part of the Robots to Thousands (RTT) project within the Robotdalen program in Sweden [7]. The studies were executed by engineering students from a masters program within “Production and Logistics Management” at Mälardalen University, supervised by a research team at the university investigating the use and application of robot automation within SMEs. A simply, standardized methodology was used for the studies and based on four different project phases: 1) problem specification, 2) process definition, 3) actual status in the area being studied, and 4) suggested solutions and an investment analysis. Each study was documented in a report based on a standardized structure. These reports were then analyzed, the results of which are presented in this paper. The analysis consisted of comparing the specified reason and problem in the study (i.e., why the company wanted to invest in automation), the potential of investing in robot automation, and the identification of the main obstacles and reasons for not implementing robot automation in each case study.

The second research project revolved around the investigation of the concept of mobile production capacity on demand. The idea with mobile production capacity is to use mobile manufacturing modules that can rapidly be combined into a complete manufacturing system and be reconfigured for a new product and/or scaled to handle new volumes. Given such a module, the production capacity could be offered as a mobile and flexible resource that can rapidly be tailored to fit the needs of the customer. The Swedish Foundation for Strategic Research funded the research project, which was named “Factory-in-a-Box”, between the years 2005-2009. The main objective of the project was to demonstrate the concept of mobile production capacity on demand through the development of real industrial demonstrators in close cooperation with academy and manufacturing companies in Sweden.

One of the demonstrators developed for this project focused on reconfigurable robotic solutions and started as a development project that resulted in a prototype solution that was implemented as a functional robotic cell within a manufacturing company [8]. Another demonstrator was developed at a small Swedish manufacturer with a profile of craftsmanship and small production volumes. The aim was to investigate the possibility of using robot automation in combination with the Factory-in-a-Box concept in order to quickly ramp-up production through portable robot solutions and increase the flexibility of the manufacturing system [9]. Both demonstrators were developed by a research team from Mälardalen University.

Automation and Lean Production

Current research shows that companies that implement lean manufacturing principles or just-in-time production (JIT) often have a competitive advantage over those that do not [10]. However, implementation of a lean production philosophy is more or less successful depending on how much the internal structure and culture of the company is changed [11]. Many western companies have realized that just trying to imitate the Toyota Production System will not give them the advantage they are looking for. Many companies are realizing that they need to implement lean within the “whole” organization; that is, they need to become a lean enterprise [12]. The term lean is often related to using less human effort in the factory and less manufacturing space, having fewer investments in tools and fewer engineering hours needed to develop a new product in less time, keeping less inventory, having fewer defects in production, and producing a greater and ever-growing variety of products [12].

Technology as automation affects competitive advantage if it has a significant role in determining the relative cost position or differentiation [13]. Since technology is embodied in every value activity and is involved in achieving linkages among activities, it can have a powerful effect on both cost and differentiation. Traditionally, high-tech automation has been used by companies that were not considered as lean [14], while companies such as Toyota have developed so-called low-cost automation [15].

Automation in lean production is about deciding the appropriate level of automation [16].

> It's not a question of whether lean is manual or not - effective lean production systems use both manual and automated processes - the task is to determine the appropriate type of automation. Taichi Ohno, the co-inventor of the Toyota Production System, said long ago that there are two sure facts about forecasts: they are almost never correct, and they always change. With this thought in mind, machines need to be developed so that the lean production system can have increments of capacity without a large capital expenditure. In other words, how can automation be developed within the production system to react to changing customer demand? (p. 1)

The phrase "lean automation" has been defined in different situations. Some pharmaceutical industries have been looking to make their production more efficient through the use of automation and have, in this context, defined lean automation as [17]:

> Lean automation is a technique which applies the right amount of automation to a given task. It stresses robust, reliable components and minimizes overly complicated solutions. (p. 26)

One of the pillars of the Toyota Production System is called jidouka, which means autonomation, also known as "automation with a human touch". The original meaning of jidouka was Automation, as shown in Figure 1. The sentence was later changed at Toyota into the spelling shown in Figure 2, the pronunciation of jidouka was the same but they added two extra lines, spelling human. This was an important statement, meaning that the automation (or autonomation) should be working the same way as a human; it should be intelligent. The three words in Figure 1 spell out "self moving transformation", while the extra two lines in Figure 2 add the human touch.

The purpose of the addition of human touch was to ensure that production would stop if there were any type of problem during production. The concept of autonomation was developed because Toyota saw a potential problem in normal automation; that is, that it does not have any built-in checking for quality problems. This could lead to hundreds of defective parts produced if automated production equipment were operating without human supervision. "At Toyota, a machine automated with a human touch is one that is attached to an automatic stopping device" [18]. This means that autonomation is an important part of the Visual Control system, or Management by Sight, where it is important that the current state of production is always visible and any problems are brought to attention as soon as they occur [19].

自動化

Figure 1. The Japanese Word Jidouka for Automation

自働化

Figure 2. The Japanese Word Jidouka for Autonomation

A conclusion regarding the discussion on automation in lean production is that a lean philosophy introduces extra demands on the workstations in the production system. Automation adopting lean principles should not reduce flexibility and robustness of the system. Lean automation uses robust, reliable components and minimizes overly complicated solutions. In order for automation to fit lean principles and practices, there is a need for development of solutions giving increased availability, reducing set-up times, improving the ability for easily reconfiguration, and offering information design to clearly present visual information and options to the operators. Thus, a possible development of robot automation towards Jidouka and "automation with a human touch" could be to give information support to operators, thereby reducing the perceived level of complexity.

Research Project 1: Automation Requirements within SMEs

Analysis showed that the main reasons for companies to address a possible implementation of automated equipment were to:

- reduce manual costs within operations (78% of all studies);
- remove ergonomically bad workstations and operations (38% of all studies);
- improve quality and achieve higher utilization (29% of all studies); and,
- reduce lead time/through-put time in operations (16% of all studies).

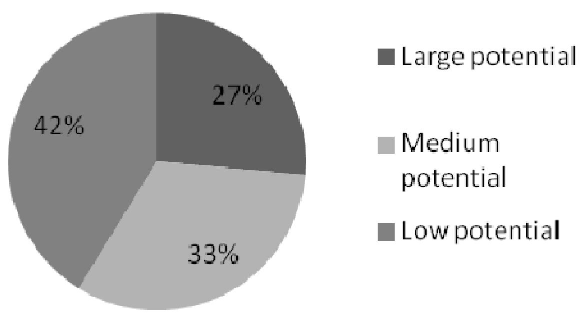

Figure 3. Investment Potential of Robot Automation to Increase Manufacturing Competitiveness within Swedish SMEs

The results from the analysis indicated that robot automation is not easily justified within Swedish SMEs. Robotic automation is often regarded as a large investment, which often is hard to justify beforehand. The reason for this is that many of the SMEs have a rather short planning horizon when it comes to product lifetimes. Many of the companies are sub-suppliers with small batch sizes. Although the total order size can be rather large, it is often divided into several smaller orders, making it more difficult to predict the total number of articles that should be produced.

The analysis consisted also of analyzing the main obstacles to economically justify the investment, as well as expressed reasons not to invest in robot automation:

- Low and unsecure volumes (56% of all studies)
- Short life-cycles, product variety and costs to reprogram the system (38% of all studies)
- Reluctance in investing in advanced technology and the need to rely on external experts (31% of all studies)
- Costs related to the need of flexibility and reconfigurability (24% of all studies)
- Problems regarding the handling of breakdowns and maintenance (16% of all studies)

Many of these obstacles/reasons are related to each other; for example, low production volumes, short product lifecycles and the need for flexibility as well as advanced technology and problems regarding handling maintenance. Based on the analysis, one could conclude that there is a need to reduce costs related to a perceived level of complexity in order to justify more investments in robot automation in SMEs.

The analysis of the different studies within SMEs also showed a need for support for:

- determining the right level of automation as well as specifying the automation solution;
- handling a lack of reliable data when analyzing operations in SMEs; and,
- investment analysis related to product life-cycles and the balance between flexibility and reconfigurability.

Another conclusion from this study was the need for a simple and structured systematic approach/methodology for investigating the possibilities of using robot automation to improve industrial competitiveness within SMEs. This ended up being a good requirement specification of a future robot system solution that could be communicated and handed over to an integrator.

Research Project 2: Two Automation Demonstrators

This research project investigated the concept of mobile production capacity on demand and a concept called Factory-in-a-Box between the years 2005-2009. The goal of the project was to develop industrial demonstrators in close cooperation with academy and manufacturing companies in Sweden.

There are several potential applications of mobility and production capacity impacting demand within the manufacturing industry, including

- covering occasional production volume peaks;
- performing maintenance close to the customer by moving equipment;

- sharing investments by moving equipment between plants;
- quickly facilitating prototype development close to product development; and,
- leasing of equipment for temporary use.

In the Factory-in-a-Box project, standardized production modules were developed with the overall objective of developing solutions and means for easy re-configuration of manufacturing systems and supply chains. Two industrial demonstrators involving the use of robotic automation and trying to realize and demonstrate the Factory-in-a-Box concept, were developed.

One of the demonstrators focused on reconfigurable robotic solutions and included the investigation of if and how reconfiguration of a robot system could be supported by software. A survey of the market of available PC software that could meet the requirements of the industrial application was conducted, but no suitable solution was found. The decision was made to develop software that could meet the industrial needs of reconfiguration, which led to the design and implementation of a prototype, called the Cell Configurator [20]. This software supported the configuration of the program logic in the working cell with an easy-to-use and intuitive drag-and-drop programming style.

The demonstrator developed within the project consisted of two robots cooperating together with other I/O-controlled equipment such as a gluing station and a folding station. The programming of the logical sequences of the cell was implemented as a graphical user interface enabling the user to program the logical sequences in the programs as icon-based flowcharts. This type of graphical programming has been shown to be more visual to the user and more intuitive to use. The programming of the robotic movement paths was implemented using simulation tools and some online programming. This installation was put into production at the industrial partner during the autumn of 2006. The demonstrator started as a development project, resulting in a prototype solution and finally an implementation of a functional robotic cell in production within the company.

The key features and vision of the Cell Configurator software is that it may be used for several different robot applications, enabling the user to have the same software solution and user interface on all its robot installations. Reconfigurability is enabled as it lets the user change the program logic of the cell in a swift and intuitive way. Also, long-term adaptability as a set of plug-in interfaces allows the user to create its own components and import them into the software. This allows the user to use any peripheral equipment that can be used programmatically and also to use any type of robot controller as long as its resources may be accessed from the PC.

A second demonstrator was developed at a small Swedish manufacturer with a profile of craftsmanship and small production volumes, with a potential of a future volume increase due to success in products and market. The aim of the study was to investigate the possibility of using automation in combination with the Factory-in-a-Box concept in order to quickly ramp-up production through portable robot solutions which increase the flexibility of the manufacturing system. The study resulted in a Factory-in-a-Box demonstrator, which was physically presented in December 2008 in Eskilstuna, Sweden.

The demonstrator set out to investigate whether automation in combination with the Factory-in-a-Box concept could be a suitable solution for how to increase the production volume of craftsmanship and small production volumes at the case company. The initial phase of the project included an initial process mapping at the company and the generation of different conceptual robot solutions. The initial conclusion of the feasibility study was that a fixed automation solution was most appropriate, if the production volumes could rise to planned levels. Still, the company wanted to keep the image of craftsmanship as a part of the trademark of the products and company. This made investment in fixed-process automation in the production process hard to justify. Further, as the company was run by only two people having competence in the manual process but no knowledge in production engineering or automation technologies, this made investing in advanced production technology risky. Thus, the main objective was a portable robot solution with a focus on simplicity and usability, to be able to guarantee smooth and fast installation.

The results included standardized equipment that could be reused for other purposes. The use of an industrial robot made the cell flexible since its range of possible applications is vast and new tasks could easily be added. The user interface, on a PC screen, was made as simple as possible to enable easy handling of the cell even for persons not familiar with industrial robot systems. For example, a touch screen was used to manage start/stop functions and the choice of labels. The use of parameterized programming made it easy to change the programming and the cell behavior. The robot was placed on a platform that, due to its weight, would not need to be secured to the floor. The small size of the cell (2774×1868×2000mm) also enabled it to fit into many environments, which was a requirement if the cell were to be leased to different customers.

Some of the conclusions from the two demonstrators presented here include:

- It is technically possible to reduce the perceived level of complexity in automation equipment by using software support and intuitive control through, for example, graphical programming.
- Portable and mobile equipment enables new commercial solutions such as leasing, which removes some of the obstacles and risks regarding investments at SMEs.
- Standardized and reusable solutions are crucial factors in achieving simple automation solutions, enabling easy reconfiguration and changes of the system to handle future product variants without large additional investments.

Requirements and Solutions for Lean Automation

The objective of this study was to investigate requirements as well as possible solutions for efficient use of automation in the Swedish manufacturing industry. It was stated that one way to handle current manufacturing challenges and improve a company's efficiency could be an increased level of automation and increased use of industrial robotics. However, robot automation investments are often regarded as too expensive and too technically advanced, especially within SMEs. Another challenge was the adaptation of automation to the principles and practices of lean production, which many manufacturing companies currently are trying to implement.

Automation within lean production was discussed, indicating the need for robust, reliable components as well as to minimize overly complicated solutions. In order for automation to fit lean principles and practices, there is a need for development of solutions giving increased availability, reduction of setup times, improvement in the ability for easily reconfiguration and information design to clearly present visual information and options to the operators. A possible development of robot automation towards Jidouka and "automation with a human touch" could be to give information support to operators to reduce the perceived level of complexity.

There is, based on the research projects presented in the paper, no reason to say that industrial robotics is not a suitable solution. However, as companies strive to become leaner and eliminate waste, complex production equipment could cause other problems in the automated process due to rigid solutions and limited transparency. Continuous flow and reduced inventory highlight inefficiencies and pose new demands on the equipment used in the production cells. The research projects presented in this paper enumerated possibilities for reducing the perceived levels of complexity in automation equipment by using software support and intuitive control via techniques such as graphical programming. Portable and standardized solutions that could be reused would be one step towards making automation more accessible.

Based on the discussion of automation and lean production as well as the empirical studies presented here, four main areas for future research are proposed that would enable more efficient use of automation in the Swedish manufacturing industry. These four areas were also proposed as central themes in the development of a lean automation concept.

1. The ability to choose the right level of automation as well as the right automation solution. These are important challenges in the development phase of an investment in automation. Knowledge and support in this area will enable the formulation of a good specification of a future automation solution.
2. The ability to develop automation solutions which are flexible and reconfigurable, enables the system being developed to be changed and adapted to new demands during its lifecycle. This requires hardware and software solutions for changeovers and changes of the automation system towards new products and new applications.
3. The ability to handle complex equipment without being an expert. The requirements are intended to reduce the perceived level of complexity, possibly through intuitive user interfaces.
4. The ability to change and implement changes in a given automation system due to changes in the products. This should be done by the owner of the equipment without large additional investments in, for example, expensive service contracts. This requires support during operations by the system integrator. If the right hardware and software solutions are chosen, the changes could be easy; otherwise, some sort of help-desk function would be needed giving online support when needed.

Summary and Conclusions

The objective of this study was to investigate requirements as well as possible solutions for efficient use of automation in the Swedish manufacturing industry. Results from two research projects were presented, which investigated how industrial automation and robotics can increase manufacturing competitiveness in industry. In the first project, requirements on automation solutions within small and medium-sized manufacturing companies were evaluated. The second project investigated possible solutions for increased flexibility and reconfigurability of robotic systems enabling production of different products and the adoption of future product variants without large additional investments.

Four main areas for future research were proposed as central in the development of a lean automation concept; 1) the ability to choose the right level of automation as well as the right automation solution, 2) the ability to develop automation solutions which are flexible and reconfigurable, enabling the system developed to be changed and adapted to new demands during the life cycle, 3) the ability to handle complex equipment without being an expert, and 4) the ability to change and implement changes in a given automation system due to changes in the products.

Future work will include development of support for choosing appropriate automation levels and automation solutions and developing a robot automation handbook. This handbook will give support to the development phase when investing in automation solutions and could include checklists and theoretical guidance on the development work. The pre-studies performed in the Robots to Thousands (RTT) project within the Robotdalen program in Sweden, is a good base for this work.

The ease-of-use part in handling the equipment as well as handling changeovers will be investigated through the development of a cell-PC software tool which will enable monitoring of the production process in the cell. This solution will provide statistics and system awareness during production to the operators and also providing functionality for alerting the operator regarding operator maintenance and changeovers between products. Later, methods for systematic robot programming will be introduced, aiming at simplifying and visualizing robot programs which are easy to modify through, for example, parameterization. The overall objective of the ease-of-use area is to reduce the perceived complexity of the manufacturing system supporting reconfigurability of robotic systems and enabling production of different products and simple configuration to handle future product variants without large additional investments.

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