Robot Automation in a Lean Manufacturing System

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Abstract: Globalization and the increasing challenge from low-wage competitors highlight the need for European industries to enhance their ability to develop and manufacture products competitively. As a consequence, many manufacturing industries are trying to implement the unique management principles and practices of the Toyota Motor Corporation’s with many different names, for example “The Toyota Production System” or “Lean production”. One question and debate within industry, is whether traditional robot automation fits the principles and practices of lean? This paper presents results from a project which has investigated if industrial robot automation has a place in a manufacturing company pursuing a lean philosophy. Two case studies are presented, based on a manufacturing company in Sweden that is currently undergoing a transformation towards a lean-based production system. The results from the first case study shows some of the challenges regarding automation that the Swedish manufacturing company face, as well as it identifies four areas considered as important to focus upon when introducing robot automation in the lean manufacturing system. The second case study pin-points some important factors (in terms of robot automation) which differ between Swedish manufacturing culture and some studied Japanese companies.

Keywords: Lean production, Industrial robotics, Manufacturing system

Introduction

Globalization and the increasing challenge from low-wage competitors highlight the need for European industries to enhance their ability to develop and manufacture products competitively. As a consequence, many manufacturing industries are trying to implement the unique management principles and practices of the Toyota Motor Corporation’s with many different names, for example “The Toyota Production System” or “Lean production”. One question and debate within industry, is whether traditional robot automation fits the principles and practices of lean? This paper presents results from a project which has investigated if industrial robot automation has a place in a manufacturing company pursuing a lean philosophy. Two case studies are presented, based on a manufacturing company in Sweden that is currently undergoing a transformation towards a lean-based production system. The results from the first case study shows some of the challenges regarding automation that the Swedish manufacturing company face, as well as it identifies four areas considered as important to focus upon when introducing robot automation in the lean manufacturing system. The second case study pin-points some important factors (in terms of robot automation) which differ between Swedish manufacturing culture and some studied Japanese companies.
manufacture products competitively. Meeting customer demands requires a high degree of flexibility, low-cost/low-volume manufacturing skills and an ability to offer short delivery times. In order to stay competitive, many manufacturing industries are trying to implement the unique management principles and practices of the Toyota Motor Corporation’s with many different names as e.g. The Toyota Production System (TPS) or Lean production.

Current research show that companies that implement lean manufacturing principles or just-in-time production (JIT) often reach competitive advantage over those that do not (White et al., 1999). However, these implementations of a lean production philosophy are more or less successful depending on how much the internal structure and culture of the company that is changed (Emiliani et al., 2005). Many western companies have realized that just trying to imitate the Toyota Production System will not give them the competitive advantages they are looking for. An increasing amount of companies are realizing that they need to implement lean within the whole organization, they need to become a “lean enterprise” (Womack et al., 1990).

One question and debate within industry is whether traditional robot automation fits the principles and practices of lean? When conducting interviews in industry one can receive comments like: “Automation and industrial robotics creates complexity” or “Robotics and lean does not fit together; they rather contradict each other”. In some cases, companies even have started to remove automation, motivated with a reference to Toyota as a company that does not use advanced manufacturing technologies. This, however, is not true since Toyota is a technology-based company that are among the most sophisticated users of advanced manufacturing technologies in the world (Liker et al., 2006).

This paper presents results from a project which has investigated if industrial robot automation has a place in a manufacturing company pursuing a lean philosophy. Two case studies are presented. The first case study is based on one manufacturing company in Sweden that is currently undergoing a transformation towards a lean-based production system. The case study resulted in the identification of four important areas which the company should focus on in order to achieve efficient and effective production.

The second case study presents results from a set of interviews and observations performed at four manufacturing companies in Japan. The purpose of the case study in Japan was to identify if there were any obvious differences between how Japanese companies, who have been working with TPS-inspired production for quite some time, are working with robot automation compared to Swedish manufacturing industries.

**Automation Within a Lean Manufacturing System**

The term lean is often related to using less human effort in the factory with less manufacturing space, less investments in tools, less engineering hours to develop a new product in shorter time, keeping less inventory, fewer defects in production, and production of a greater and ever growing variety of products (Womack et al., 1990). Lean practice has primarily two objectives: eliminate waste and create value for end-use customers. Studies show the more comprehensive the adoption of
JIT and lean principles is at a company, the greater are the overall returns (Fullerton et al., 2001).

Technology as automation, affects competitive advantage if it has a significant role in determining the relative cost position or differentiation. 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 (Porter, 2004). Using highly automated manufacturing systems is a way for companies with high labor costs to compete (IVA, 2005).

Traditionally, high-tech automation has been used by companies who are not considered as lean (Muffatto, 1999), while companies such as Toyota have developed so called low-cost automation (McCarthy and Rich, 2004). Womack et al. (1990) identified in their MIT study that many western automotive companies extensively used automation, but Japanese companies that had the highest productivity, had the lowest level of automation. However, they also believed that the automotive industries would automate almost every operation in the factories in the future (Womack et al., 1990).

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 (Dulchinos and Massaro, 2005, p. 26);

“Lean automation is a technique which applies the right amount of automation to a given task. It stresses robust, reliable components and minimises overly complicated solutions.”

One of the pillars of the Toyota Production System is called Jidouka, which comprises autonomation, also known as “automation with a human touch” (Ohno, 1988). The original meaning of jidouka was “Automation” as shown in Fig 1 (a). The sentence was later changed at Toyota into the spelling shown in Fig 1 (b), 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 2. The three words in Fig 1 (a) spell out: “Self moving transformation”, while the extra two lines in Fig 1 (b) adds the “human touch”.

The purpose of the “human touch” is to ensure that production will stop if there is any type of problem during production. The concept of autonomation was developed since the Toyota Corporation saw a problem in that normal automation do not have any built in checking for quality problems. This may lead to hundreds of defect parts produced if automated production equipment is producing without human supervision. “At Toyota, a machine automated with a human touch is one that is attached to an automatic stopping device” (Ohno, 1988). 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 (Liker, 2004).
A lean philosophy introduce extra demands on the production system and the workstations that are part of this system. Lean automation does not reduce flexibility and robustness of the system. Lean automation uses robust, reliable components and minimises overly complicated solutions. In order to fit lean principles and practices there is a need for development of robotized working cells with solutions giving increased availability, reduced set-up times, improving the ability for easily reconfiguration, and information design to clearly present visual information and options to the operators.

Research Method

This paper is based on case study research, including interviews, observations, and to some extent practical development work at a manufacturing company. A case study is a preferred research method when a specific phenomenon is to be closely studied within its natural context (Yin, 1994). Case studies can be characterized by the fact that they often study a phenomenon when and where it happens and that the exact context or delimitations are not fully known (Yin, 1994).

The first longitudinal case study has been conducted with close co-operation with the case company, called Company A. A common project was initiated where both researchers from the university and personnel from the case company was involved, as well as personnel from a third party robot systems integrator. Open interviews was conducted with production management, operators, and the production development teams. Several workshops were conducted where the company representatives from both companies and the researchers from the university discussed different topics regarding robot automation and the lean transformation. During twenty weeks of the spring 2008, two master thesis students worked at the company in order to map the current state of production with focus on automation. It is important to stress that Company A has had problems related to robot automation, hence the reason for participating in this project. Company A is not representative for all large Swedish manufacturing companies, but the problems found here is probably relevant for other companies as well.

The second case study was performed as a set of interviews and observations at four companies in Japan. The companies where chosen for different reasons; Company B is an automotive company known for its highly developed production philosophies (TPS). During this company visit the researchers was granted limited access to production facilities and personnel. However, a TPS-expert participated and provided good opportunities to get in-depth information about the manufacturing system. This company visit provided limited information...
to the case study, however, the TPS-expert was present during several of the visits and provided good insight into the TPS-principles.

Company C produces electronic devices for consumer and automotive industries. This company is partly owned by Toyota and known for its advanced adoption of lean production principles. At this company the researchers was granted a high level of access, with interviews with both production management and production engineers. The researchers were also able to access the production facilities and get a close look at the manufacturing equipment. This company provided a lot of information to the case study.

Company D is partly owned by Toyota as well and produce air-condition units for the automotive industries. During this company visit the researchers was granted a high level of access to the manufacturing facilities, as well as interviews with production management and production development personnel. Further, a sales manager from the robot manufacturer supplying all the industrial robots to the company participated in the visit and was available for interviews. This visit provided a lot of information to the case study.

Company E is a robot developer originating in Japan. The visit was at their advanced R&D plant and the interviews where regarding future developments within the robotics area. Moreover, visits at the company’s prototype labs provided some insight in the current progress at the company. This company visit provided limited information for the case study.

Case Study 1

The first case study was performed in the form of interviews, observations, workshops together with the case company (Company A), as well as development work at the case company. The case company is a large Swedish manufacturing company, supplying components to the automotive industry. The case company has undertaken a large production development project aimed at transforming their manufacturing system towards TPS-inspired production philosophies. The case study was initiated as a response to some discussions at the company as to whether industrial robots were appropriate to use after the transformation. Some of the results of this case study have previously been published in (Hedelind and Jackson, 2008), where a more in-detail description of the case study can be found.

Background

Earlier studies shows that companies that implement what is called lean manufacturing principles or just-in-time (JIT) production can reach competitive advantage over those that does not (White et al., 1999). However, these transformations are more or less successful depending on how much the internal structure and culture of the company is changed (Emiliani and Stec, 2005). The transformation at the case company was to be a large change in both manufacturing system layout where almost every machine and station where to be relocated, as well as in company organization.

During the re-structuring of the company a debate was initiated regarding whether their current automation equipment was suitable for the new production philosophies. Voices at the company where saying that: “...
complexity to the manufacturing system” and “robotics and lean manufacturing does not fit together, they rather contradict each other”. The general belief was that working stations including industrial robots becomes too rigid and thus creating production systems that are inflexible and incapable to adapt to changes. Also, the company experienced a lot of difficulties with their present automation equipment, difficulties which resulted in low availability of the work cells.

Results

The results of the case study included a better understanding of why there was a reluctance of using robot automation at the company. The production management of the company was sceptic to the current automation solutions due to low availability. The reasons identified during the case study for this low availability included:

- Many machines and operations in each cell. When several machines are connected, their individual availabilities are multiplied for the whole cell, making it more sensitive to small failures and shorter stops.
- A diversity of types of robot solutions in the manufacturing system, originate in that several different third party system integrators had been contracted with a very low level of control over their respective systems built.
- Many small stops in the cells and no real follow-up on how to deal with these continues losses.

Issues regarding the general use of robot automation at the company included:

- An over-reliance on external consultants, due to low level of expertise of the operators and inconsistent design of the robotic working cells due to sparse design rules supplied to the system builders.
- Low level of understanding of current state since no measuring tools where used to monitor performance indicators.
- High cost of manufacturing, due to over-reliance on external consultants and losses in productivity.

The first case study ended in the identification of four key-areas where development is needed to ensure that robot automation can be integrated fully in the lean manufacturing system:

- **Ease-of-use**, this area focuses on how to harvest all the information needed from the robotic working cell and then present it to the operator. It also includes aspects such as how to set-up the robot programs so that it is easy to implement changes in the cell, for example adding new products to be produced.
- **Standardization**, used to ensure that all robotic working cells in a manufacturing system are designed in a similar fashion, enabling operators to work with the different cells and recognize how the system is built.
- **Robust operations**, systematic methods for how to work with maintenance in order to ensure high availability of the manufacturing system. This also includes methods for deciding which key-
performance indicators to monitor in order to get the correct feedback of how well the system works.

- **Visualization**, ways of showing every person that is part of the manufacturing system what is currently happening and why.

Two important observations can be made when looking at the list of key-areas above. Firstly, these areas have a lot of interconnections – they overlap and some of the areas may enable the others. Secondly, they are not specific for robot automation; however, robot automation increases the need to focus on these aspects of designing a manufacturing system.

**Case study 2**

The second case study was performed in order to investigate the differences between how Japanese and Swedish manufacturing companies use robot automation. The study was performed as company visits where the researchers had access to four different Japanese companies’ production facilities as well as being able to interview key persons working at the companies.

**Findings**

Visiting Company B provided the researchers with a better understanding of TPS, and how TPS can be implemented. During this visit a TPS-expert, formally trained at Toyotas production engineering training, participated and provided a lot of information and insight. The TPS-expert was also present during the visit at Company C.

The visit at Company C showed that even though the company was primarily doing manual assembly, they did have some automation; both workstations with fixed automation primarily used for testing and some robot cells with assembly operations. Interviews with production management reviled that the company had just started using robots in the assembly lines. The motive for introducing robots was as part of an overall strategy for reducing cost. The production development department had been faced with the responsibility to reduce cost of assembly with 20 per cent over five years. Introduction of robots was seen as one way of achieving this. The production manager of the whole plant was very optimistic that the production development team would meet with the demands on cost-cut.

Interviews with the production engineering personnel showed that the design and construction of the robot workstations were done entirely by themselves. The company had chosen a Japanese robot supplier because of its geographical closeness in case of service or support. However, they did not use the robot supplier, or any third party integrator, when building the workstations. They only contacted the robot supplier if they needed support regarding any advanced programming issues.

The overall “feeling” of the assembly plant at Company 2 was that even though the assembly line was mostly manual; the level of technology and automation was rather high. The company had a lot of poke-yoke solutions in each station, making sure that the operator performed each operation correctly. As the company designed all those manual stations with those poke-yoke and automation solutions,
they do have a lot of competence within the production engineering department that can be utilized for introducing industrial robot automation as well.

The visit at Company D provided an opportunity to interview both the company using industrial robots, as well as the robot supplier. The discussions with the robot supplier showed that Company D was a rather demanding customer, which was appreciated by the supplier. The two companies have a very close relationship, and Company D is the robot supplier’s largest customer. The production facilities at Company D had a rather high level of automation, with a mixture of fixed automation and robotics. The company showed an active interest in improving the productivity of the factory and had developed new production system philosophies in the past (and published at scientific conferences) regarding the use of automation. The company built all their workstations themselves and was very interested in learning about new production technologies.

The visit at Company E provided the researchers with some insight in current state-of-the-art in the area of industrial robot applications. This visit was primarily a way of discussing robot related issues with a Japanese robot developer, not necessarily related to lean production (even though a lot of the applications they were interested in was related to continuous improvement and optimization).

Results

One can see a distinct difference between the Swedish Company A and the Japanese Company C and Company D in that the Japanese companies are designing and building robot cells in-house. They have built up a high level of knowledge and experience in the company regarding advanced manufacturing technologies and feel confident with their own production equipment. The large Swedish manufacturing company investigated have problems with their production, which in many occasions can be derived from lack of competences related to advanced manufacturing technologies.

Conclusions

This paper has investigated whether traditional industrial robotics is applicable in a lean production system. There is, based on a case study presented in the paper, no reason to say that industrial robotics is not suitable. However, as companies strive to become leaner and eliminate waste; complex and complicated production equipment often gives disturbances due to rigid solutions. Continuous flow and reduced inventory highlight inefficiencies and poses some new demands on the equipment used in the production cells. Four main areas where the robotic working cells at the company can be improved have been identified.

Two case studies have been performed in order to investigate how to introduce robot automation into so-called world class manufacturing systems. The first case study was conducted together with a large manufacturing company in Sweden, currently undertaking a large production development project in order to transform its manufacturing system towards the lean production principles. This case study aimed at investigating the current needs of that company in terms of how to make robot automation more effective. The second case study was conducted as interviews and observations at companies that are actively working with Toyota-
inspired manufacturing systems. The aim of the second case study was to further investigate the differences between the Swedish manufacturing company, and the Japanese counterparts which have been working with TPS-inspired manufacturing principles for some time.

One can see that the case company, as reported in (Hedelind and Jackson, 2008), had some problems related to their current robot automation solutions. Based on the issues identified, a set of four key-areas where identified as important to focus on when developing robot automation to be used in the lean manufacturing system; ease-of-use, standardization, robust operations, and visualization. Those four areas are not specific to robot automation, but the effects of not incorporating them into automation aggravate any problems due to more complex systems, compared to manual production. In some cases, robot automation cells are black boxes in the manufacturing system; components are fed into the cells and outcomes refined components with value added. This may be acceptable as long as the cell is working correctly. However, when working according to the TPS principles of continuous flow and just-in-time; every small problem in a cell is magnified. If the company does not have full insight in all aspects of their manufacturing system, such small problems may turn into big losses.

Future work will be to continue working on the four areas identified to come up with methods for how to secure that those areas are not forsaken when working with industrial robot automation. One of the major differences between the Swedish company and the Japanese counterparts is that the Japanese companies have a greater insight and knowledge about their manufacturing systems. The four areas identified as important to sustain a high availability in the manufacturing system are aiming to, in different ways, ensuring that the company has the possibility to work with continuous improvement.

The ease-of-use part is investigated through the development of a cell-PC software tool used to monitor the production process in the cell, thus providing the operator with system awareness during production 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 supporting the system integrator in creating 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.

Standardization will be introduced through the compilation of a handbook for how companies may work with robot integration together with suppliers. One important part in this is how to create a specification or scope of supply which can be communicated to the systems integrator to ensure that the resulting installation is according to company standards.

Robust operations focus on development of working methods regarding maintenance and routines for efficient changeovers between product types.

Visualization is currently working on the design of physical areas for continuous improvement. Theses areas are to be introduced in the production lines to ensure that the persons working on the lines have natural places to have meetings and work with continuous improvement.
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