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IFAC-PapersOnLine 48-3 (2015) 1870–1875

Lean Automation enabled by Industry 4.0 Technologies

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Abstract: The Lean Production paradigm has become the major approach to create highly efficient processes in industry since the early 1990s. After the sudden end of the Computer Integrated Manufacturing (CIM) era, which finally was doomed to fail due to its unrulable complexity of the required automation technology, the Lean approach was successful because of its high effectiveness by reducing complexity and avoiding non-value-creating process steps. Today, the term Industry 4.0 describes a vision of future production. Many people are at least skeptical or even hostile towards this new approach. This position paper gives an overview over existing combinations of Lean Production and automation technology, also called Lean Automation. Furthermore, it discusses major Industry 4.0 corner stones and links them to the well-proven Lean approach. Examples of combining both are smart watches for supporting the Andon principle or Cyber Physical Systems (CPS) for a flexible Kanban production scheduling.

Keywords: Industry 4.0; Cyber Physical Systems; Lean Automation; Lean Production

1. INTRODUCTION

Lean Production principles are widely accepted in industry since their first broader appearance in the early 1990s. Key characteristics of Lean Production are the strict integration of humans in the production process, a continuous improvement and focus on value adding activities by avoiding of waste. Its simplicity and up to 25 per cent higher productivity are some reasons why Lean Production has become status quo of production systems (Gröbner, 2007).

Today, we face a new paradigm called Industry 4.0, which on the first glimpse seems to be a rebirth of the old CIM idea. Driven by modern information and communication technologies (ICT), Industry 4.0 is a network approach where components and machines are becoming smart and a part of a standardized network based on the well proven internet standards. By strict standardization these objects can be handled as Lego-bricks to set up larger systems. The Plug'n'Play principle, well known from home computer field, will be applied to ease engineering and set up. Besides, looking deeper into the Industry 4.0 vision, parallels to Lean Production can be identified.

Already in the early 1990s, first approaches for integrating automation technology into Lean Production arose and were called Lean Automation. Nowadays, there are new areas of application for Lean Automation due to the potential of Industry 4.0 technologies. For example, by implementing flexible, powerful and affordable Cyber Physical Systems (CPS). New areas of application include enhancing existing Lean Production solutions as well as extending Lean Production's applicability to different production types.

Chapter 2 of this paper gives an overview over existing possibilities and examples of the combination of automation technology and Lean Production. Besides, chapter 3 outlines use cases and a framework how Industry 4.0 can add value to Lean Production in future. In this framework, CPS play an important role.

2. STATUS QUO OF LEAN PRODUCTION AND INDUSTRY 4.0

2.1 Advantages and disadvantages of Lean Production

Founded in 1950s by Ono at Toyota, Lean Production is a collection of synchronized methods and principles for controlling production sites. It describes in a technology-independent way how a production has to be organized and processes have to be handled to reach shortest lead time with minimum costs and highest quality (Ōno, 1988).

Its simplicity and high effectiveness had been reasons why Lean Production became famous in 1990s. Today, it is still a fundament of production systems at many OEMs and is used among various business domains (Herlyn, 2011). Key concepts are reduction of waste, a continuous improvement process and a change in production control towards demand oriented production. Lean Production contributes faster reaction on changing market demands, smaller batches and transparent plus standardized processes to mass and batch production (Womack et al., 2007; Ōno, 1988).

Today, it seems as if Lean Production reached its limit: Strong deviations in market demands are in conflict with required levelled capacity utilization. Thus, a production which is decoupled from market demand is needed (Erlach, 2013; Ōno, 1988; Dickmann, P., 2007a). This is in conflict

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.06.359

with an also required order-oriented production and direct connection of production to market demands. Although Lean Production supports a higher variety of products, its fixed sequence of production and fixed cycle times are not suitable for individual single-item production. Besides, Lean Production was invented in the 1950s and thus does not take into account possibilities of modern ICT. In traditional Lean Production, changes in production processes, buffer stocks or cycle times require laborious adjustments of Kanban cards or Kanban bins (Dickmann, E., 2007). Hence, Lean Production's suitability for future shorter product life cycles and individual single-item production is limited.

2.2 Capability of Industry 4.0

The young German term Industry 4.0 describes the increased integration of ICT into production. By this means, it could complement the established Lean Production to match future requirements. In spring 2014, VDMA, Bitkom and ZVEI, three leading German associations of mechanical engineering, ICT and electrical industry, released a definition for Industry 4.0. According to them, Industry 4.0 aims for optimization of value chains by implementing an autonomously controlled and dynamic production. Enablers are the availability of real time information and networked systems (Acatech-Plattform Industrie 4.0, 2014). Instruments to reach this increased automation are CPS. Equipped with microcontroller, actuators, sensors and a communication interface, CPS can work autonomously and interact with their production environment (Broy, 2010; Lee, 2008). As a result, a factory becomes 'smart'.

The department of Innovative Factory Systems (IFS) at the German Research Center for Artificial Intelligence (DFKI) identified four enablers for the Smart Factory: Smart Products know their production process and negotiate it with Smart Machines. The Smart Planner optimizes processes in nearly real time. In this environment, humans take a central position. Supported by innovative ICT they become Smart Operators who supervise and control ongoing activities.

2.3 Lean Automation as combination of two disciplines

Lean Automation picks up the idea of combining automation technology with Lean Production. The term occurred in the mid-1990s, shortly after the peak of Computer Integrated Manufacturing (CIM) (see e.g. Franke, 1993; Groebel, 1993; Schling, 1994). In the last decade, science did not pay much attention to Lean Automation anymore. However, in the context of Industry 4.0 new solutions are available for combining automation technology with Lean Production, which are described below.

The digitalization of the Kanban system is known already since several years. Conventional, physical cards for an order-oriented production control are replaced by virtual Kanban (Lage Junior and Filho, 2010). Depending on the implementation of this so called e-Kanban system, missing or empty bins are recognized automatically via sensors. The e-Kanban system sends a virtual Kanban to trigger replenishment. By using ICT, lost Kanban do not cause mistakes in production control anymore as long as inventory in manufacturing execution system matches real inventory. In addition, adjustments of Kanban due to changes in batch sizes, processes or cycle times are easily possible (Dickmann, P., 2007a).

In 2012, University of South Denmark together with toy manufacturer Lego A/S developed approaches for integrating automation technology in u-shaped assembly stations, also known as Chaku Chaku lines. Especially human machine interaction was in the focus of this project. As a result, they developed a local order management system which shifts typical tasks of ERP systems to employees at Chaku Chaku lines. According to them, automation of value adding tasks is particularly very reasonable due to the fact that investments are amortized within shorter time. Besides, the repeat accuracy and precision of machines is higher than of humans. On the other hand, complex processes, exception handling and logistic tasks are typical functions where automation is not reasonable (Bilberg and Hadar, 2012).

In 2013, Würth Industrie Services GmbH & Co. KG presented the optical order system iBin as an extension for Kanban bins (Fig. 1). A camera in the module detects the charging level of the bin and iBin reports wireless the status to an inventory control system. Besides, iBin is also able to send orders automatically to suppliers. As a result, buffer stock can be reduced and spare parts can be scheduled order-oriented (Würth Industrie Service GmbH & Co. KG, 2013).

The ongoing research project Lean Intelligent Assembly Automation also addresses Chaku Chaku lines. The consortium, which consists out of e.g. Adam Opel AG and Fraunhofer Institute for Manufacturing Engineering and Automation IPA, develops robot-based solutions to support employees in assembly tasks within Chaku Chaku lines. Objective is to enrich manual assembly tasks in order to make them more lucrative for bigger batches (Fraunhofer Institute for Manufacturing Engineering and Automation).

Wittenstein AG and BIBA – Bremer Institut für Produktion und Logistik GmbH work among others in the state-funded project CyProS on a flexible material supply system for production lines. Instead of fixed intervals, an IT system calculates round trip intervals for the transport system based on real-time demands. In the first prototype, collection of data during this so-called milk run is done by scanning QR codes. Interaction with employees of the transport system is

Fig. 1 iBin system installed in a bin (source: Würth Industrie Service GmbH & Co. KG) realized by conventional tablet PCs. With this order-oriented material supply system stretches of way can be reduced by approximately 25 per cent at the same level of supplier's reliability (Lappe et al., 2014).

As shown above, the combination of automation technology and Lean Production can be beneficial. Contrary to popular belief, Lean Production does not exclude automation. In 1960s, Ono claimed that process should be automatized and supervised by employees. He called this principle Autonomation (Ōno, 1988). This corresponds to Industry 4.0, by which humans - supported by innovative technology - take the same role (Schlick et al., 2014; Gorecky et al., 2014). The Synchronized Production System, a further development of Lean Production for application in countries with high wages, furthermore integrates approaches for integrating automation technology. With the term Low Cost Intelligent Automation Takeda claimed that applications for automation should be developed with easy to realize instruments. Standardized, cost-efficient solutions should be favoured over individualized solutions. Both, Lean Production and Industry 4.0, favour decentralized structures over large, complex machines and both aim for small modules with low level of complexity (Takeda, 2006; Dickmann, P., 2007b; Zühlke, 2010).

3. COMBINING INDUSTRY 4.0 AND LEAN PRODUCTION

3.1 Advantages of combining both

As described in the previous chapter, integration of Industry 4.0 solutions matches Lean philosophy and the mentioned examples proved feasibility. Industry 4.0 can be integrated in Lean Production and beyond that improve Lean Production by increased integration of ICT.

This benefit accelerates the shift of Industry 4.0 from science to reality. In practice, new solutions must add value to users and must have an acceptable risk. The integration of Industry 4.0 solutions, which are in general connected with high investments, is especially lucrative in areas where cost-saving and simple methods of Lean Production are not or not completely fulfilling today's requirements.

Applying Industry 4.0 to established Lean Production could lower risks of integration due to existing advice for the organizational integration. Besides, production processes in Lean Production are in comparison to other kinds of organization more standardized, more transparent and reduced to essential work. As a result, they are less complex and support the installation of Industry 4.0 solutions.

3.2 Use cases for applying Industry 4.0 solutions

The identified enablers can be applied to several methods of Lean Production. The following section describes examples of possible combinations.

1) Smart Operator

Within the Andon method, by which employees in case of a failure should be notified as soon as possible, the Smart Operator could reduce time from failure occurrence until failure notification. Equipped with smart watches, employees receive error messages and error locations close to real time. In comparison to wide-spread signal lamps, recognizing failures does not depend on location of employees anymore. In addition, CPS equipped with proper sensors recognize failures and automatically trigger fault-repair actions on other CPS.

A continuously flow of pieces could be supported by assisting systems for employees based on e.g. augmented reality. Information about cycle times within the visual field of employees support just-in-time proceeding of goods. In addition, new employees get individualized information about necessary tasks to get along in timed productions. For the necessary identification of performed tasks and individualization of displayed information, DFKI successfully demonstrated a solution at the manual working station in the living lab *SmartFactory^{KL}* (Fig. 2).

2) Smart Product

In the context of continuous improvement processes, also called Kaizen in Japanese, Smart Products could collect process data for the analysis during and after its production. In contrast to manual data acquisition for value stream mapping it is possible to gather information individualized per product and production line automatically. On the one hand, this way of data acquisition is less labour-intensive and on the other hand, data are more precise.

Furthermore, a Smart Product could contain Kanban information to control production processes. An example of a completely de-central controlled production based on Smart Products was demonstrated by *SmartFactory^{KL}* at Hannover Messe 2014 in Germany. The presented working stations produced autonomously according to a work schedule on the product. Although it was push-controlled production, this concept could be adopted for an order-oriented control system.

Fig. 2 Augmented reality at SmartFactory^{KL} manual working station

3) Smart Machine

According to Poka Yoke, technical installations help employees to avoid mistakes (Ōno, 1988). With their computing capacity and connectable sensors, CPS could be integrated fast and flexible in fault-prone processes for supporting. Optically identical components can be identified e.g. via QR codes or RFID.

Industry 4.0 could furthermore support Lean Production's requirement for a flexible, modular production. Since several years *SmartFactory*^{KL} demonstrates modular working stations based on standardized physical and IT interfaces, which can be flexibly reconfigured to new production lines via Plug'n'Produce (Fig. 3). According to the Single-Minute-exchange-of-Die (SMED) principle, setup time should be reduced to less than ten minutes. Plug'n'Produce transfers SMED from a single working station to whole production lines.

4) Smart Planner

Although Lean Production aims for a one-piece flow and a highest possible product variety, it is not suitable for individual single-item productions. With the Smart Planner, traditional Kanban systems with fixed amount of Kanban, fixed cycle times and fixed round trips for transporting goods turn into dynamical productions automatically adopting to current production programs. Decentralized, in working stations integrated CPS could negotiate cycle times and thus find the optimum between highest possible capacity utilization per working station and a continuous flow of goods. Within the state-funded project RES-COM, DFKI already demonstrated how a semantical description of working stations supports optimization of production processes by different business objectives, like throughput time or efficacy. Applied to Lean Production, this approach could enable Lean Production to be implemented not only in mass and batch production, but also in job shop production.

3.3 A framework is missing

Although solutions according to Lean Automation already exist and research is still ongoing, they are mostly

Fig. 3 Plug'n'produce at SmartFactory^{KL} production line

applications for single, isolated aspects. To ensure modularity and exchangeability, a framework which supports the integration of Industry 4.0 solutions into Lean Production is required. With the previously mentioned concept of Low Cost Intelligent Automation, Takeda already describes a comprehensive framework for the integration of automation technology (see Takeda, 2006). Unfortunately, this concept does not consider modern ICT, especially innovative assistance systems.

Especially the potential of CPS in production is not fully explored yet. First approaches are based on the service oriented architectures and describe a generic architecture (see e.g. La and Kim; Hu et al.). In the production domain, there are frameworks based on agent oriented architectures such as e.g. PROSA (Van Brussel et al., 1998). E.g. Lewandowski et al. describe such a CPS-framework for material handling (see Lewandowski et al., 2013).

Nevertheless, a comprehensive, integrated framework which describes where and how CPS can be integrated is still missing (Schlick et al., 2014; Brusaferri et al.). As experiences from CIM-era have shown, such a framework should consider technology, human and organization (Deuse et al., 2015). The combination of CPS and Lean Production in one framework can satisfy these requirements.

3.4 Recommendation for a framework

A framework for Industry 4.0 as a supplementation to Lean Production should, on the one hand, contain recommendations which Industry 4.0 solutions could reasonably support Lean Production. On the other hand, it should mention examples of it. Comparing Industry 4.0 enablers with methods of Lean Production gives an overview over possible connections (Table 1). Next, identified approaches should be described more in detail and requirements and additional benefit have to be evaluated.

Besides this isolated applications, the framework should define interfaces how this solutions can complement each other and how to embed them into an existing environment. Similar to service oriented architectures (SOA), in the domain of Lean Production CPS can offer required services of a working station to nearby and superior systems (Fig. 4).

By this, working stations can be flexibly added to production lines and are able to process commands from a superior production control system. Furthermore, CPS can exchange data with sensors, actuators or PLCs or can interact via human machine interface with employees at working stations. As a result, manual working stations can be updated with automation technology and vice versa, without changing superior manufacturing execution system. CPS decouple communication between working stations and IT systems. Besides, the interfaces of these working stations are independent from employees and devices working in this working station.

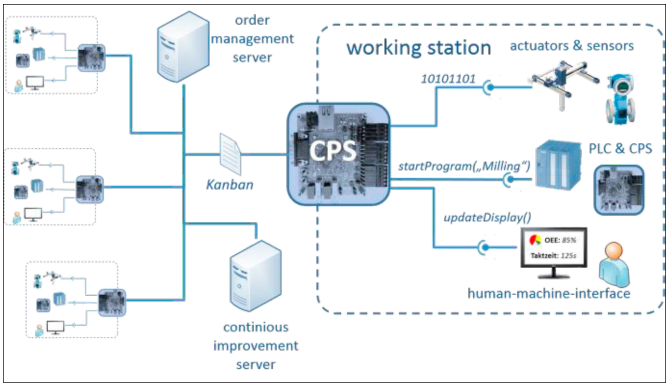

Fig. 4 Example of the integration of CPS as interface of working stations

Beyond a standardized hardware interface like RJ45, HDMI or GPIO, CPS require standardized software interfaces. TCP/IP and OPC UA are already existing, established examples of communication protocols. Information models like MTConnect or ISA88/ ISA95 can furthermore describe structures of industrial components (see MTConnect Institute, 2011; ISA, 2014).

A domain specific description, in this case for Lean Production, is missing. This framework has to describe roles of devices and their responsibilities as well as how certain tasks are triggered. E.g. in Lean Production, each working station has to be able to receive Kanban, interpret them and start the production. This tasks are independent from the actual configuration of the working station itself whether there is a machine or a human. Furthermore, failures at a working station have to be proceeded immediately to responsible employees and a superior continuous improvement system. A flexible production in addition requires an adaption of cycle times and production processes. For this it must be defined, who triggers changes and how working stations receive these messages.

A software framework for CPS-equipped working stations, i.e. a collection of ready-made software building blocks and a given structure for implementation, could support engineers. The framework defines which interfaces CPS in Lean Production must offer and implements them partly. To control working stations, it contains an information model for exchanging data with actuators, sensors, PLCs or other CPS within the working station. As DFKI already proved, necessary hardware drivers for e.g. field devices can be rapidly integrated via a central repository (Schmitt et al., 2014).

With this framework engineers could focus their work on implementing the production process instead of implementing individual communication protocols, hardware drivers or adjustments of other systems' interfaces.

4. SUMMARY AND OUTLOOK

In the previous chapters the terms of Lean Automation and Industry 4.0 have been described. Selected examples showed that the integration of innovative automation technology in Lean Production is an up to date and promising topic.

Table 1 EXAMPLES OF USE CASES TO COMBINE INDUSTRY 4.0 WITH LEAN PRODUCTION

Industry 4.0	**Lean Production**	
	Principle: Just-In-Time	**Principle: Jidoka**
	Method: Kanban system	**Method: Andon**
Smart Operator	Employee gets information about remaining cycle time via augmented reality	Wearable computing systems receive failures and display it in real time to the employee
Smart Product	Smart Product contains information of Kanban to realize an order-oriented production	-
Smart Machine	Machines offer a standardized interface for receiving and sending Kanban	Machines send failures directly to Smart Operators and call other systems for fault-repair actions
Smart Planner	IT systems reconfigure production lines and update Kanban according to the new configuration	-

Nevertheless, there is a lack of a comprehensive framework which combines Industry 4.0 solutions with methods of Lean Production. Especially a comprehensive concept for flexible integration of manual as well as automated working stations is missing. With CPS, there are hardware solutions as an interface for working stations available. Required communication protocols exist partly. Only a domain specific standard for an automated decentralized production control in Lean Production is absent. In short, Industry 4.0 and Lean Production do not eliminate each other. Together they can add value to users.

In future, IFS at DFKI will deepen its research in the field of Lean Automation. Transferring existing Industry 4.0 solutions into Lean Production and implementing CPS as standardized building blocks for working stations will be focused.

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