Lean Transformation Integrated with Industry 4.0 Implementation Methodology

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Abstract Succeeding a cultural and people-oriented transformation, lean producers adopt the philosophy of doing more with less by eliminating non-value-added activities from production processes to maintain effectiveness, flexibility, and profitability. In the context of Industry 4.0, new solutions are available for combining automation technology with lean production. Moreover, when effective usage of resources (finance, labor, material, machine/equipment) is concerned, it is obvious that Industry 4.0 should be applied to lean processes. In this context, this paper attempts to emphasize the interaction between lean production and Industry 4.0 and proposes a methodology that provides guidance for Industry 4.0 in a lean production environment. Moreover, Industry 4.0 technologies and automation-oriented lean production applications are also included.

Introduction

Lean manufacturing, which evolved from the conceptualization of the Toyota Production System by Taichii Ohno's initiatives at Toyota Motor Company, can be described as a multi-faceted production approach comprising a variety of industrial practices directed towards identifying value-adding processes from the purview of the customer and to enable the flow of these processes at the pull of the customer through the organization (Sanders et al. 2016).

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F. Calisir and H. C. Akdag (eds.), *Industrial Engineering in the Industry 4.0 Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-319-71225-3_9

From a technological point of view, lean production can be regarded as a complement to automation. Zuehlke (2010) suggested that the complexity of the production systems should be reduced by lean practices and stated that relying too much on technology cannot always improve the performance but may make the system more complicated. Lean production suggests five different levels of automation that should be considered when deciding on an appropriate automation strategy, as shown in Table 1 (Rother and Harris 2001). Meanwhile, there is a great divide between level-three and level-four automation. When making the jump to level-four automation, the cost (maintenance, engineering, machines, etc.) often increases while flexibility can decrease.

In fact, applications for the integration of Industry 4.0 into lean production already exist and have been described by the term "lean automation". Lean automation aims for higher changeability and shorter information flows to meet future market demands. Contrary to popular belief, lean production does not exclude automation. According to the automation principle of lean production, repeated and value-adding tasks should be automated. With the term "Low Cost Intelligent Automation (LCIA)", it is suggested that standardized, automated, flexible, and cost-efficient solutions should be favored over customized solutions (Takeda 2006). However, LCIA only focuses on mechanical and electrical systems and does not consider information and communication technology. Both lean production and Industry 4.0 favor decentralized structures over large, complex systems and both aim for small, easy-to-integrate modules with a low level of complexity (Takeda 2006; Kolberg et al. 2016).

Taking into account the above-mentioned manners, this paper emphasizes the relationship between Industry 4.0 and lean manufacturing and proposes a methodology that provides a waste-hunting environment for Industry 4.0 applications. The rest of the paper is organized as follows. In Section "Literature Review", relevant literature is reviewed. The proposed methodology is presented in Section "The Proposed Methodology". Cases combining lean production and automation or Industry 4.0 are described in Section "Automation-Based Lean Production Applications". Finally, the conclusions are presented in Section "Conclusion".

Table 1 Levels of lean automation

Level	Loading machine	Machine cycle	Unloading machine	Transferring part
1	Operator	Operator	Operator	Operator
2	Operator	Automatic	Operator	Operator
3	Operator	Automatic	Automatic	Operator
The great divide (cost and flexibility change drastically)				
4	Automatic	Automatic	Automatic	Operator
5	Automatic	Automatic	Automatic	Automatic

Literature Review

Some research has been performed to emphasize the interaction between lean manufacturing and Industry 4.0. For example, Sanders et al. (2016) analyzed the link between Industry 4.0 and lean manufacturing and investigated whether Industry 4.0 is capable of implementing lean. A methodology has been proposed to integrate lean manufacturing and Industry 4.0 with respect to the supplier, customer, and process as well as human and control factors. The authors also stated that researches and publications in the field of Industry 4.0 hold answers to help overcome the barriers to implementation of lean manufacturing. Similarly, Rüttimann and Stöckli (2016) discussed how lean manufacturing has to be regarded in the context of the Industry 4.0 initiative. Sibatrova and Vishnevskiy (2016) suggested the integration of lean management and foresight while considering the conditions of trends in Industry 4.0 and human and time resources. Doh et al. (2016) not only reviewed the relevant literature from the industrial revolution to the new Industry 4.0 but also considered the need for the use of automation in lean production systems and supply chain characterization with the aim of developing a framework for the integration of information systems and technologies. Blöchl and Schneider (2016) devised a new simulation game with a learning focus on lean logistics with Industry 4.0 components to teach the adequate application of Industry 4.0 technology in production logistics. Veza et al. (2016) carried out an analysis of global and local enterprises based on a literature review and questionnaires in order to develop a Croatian model of the Innovative Smart Enterprise (HR-ISE model). In that study, a selection of six basic lean tools is made and the foundations of a generic configuration of the HR-ISE model are defined. Rauch et al. (2016) presented an axiomatic design-oriented methodology that can be regarded as a set of guidelines for the design of lean product development processes. Linked with Industry 4.0, these guidelines show how a lean and smart product development process can be achieved by the use of advanced and modern technologies and instruments. Similarly, Synnes and Welo (2016) discussed organizational capabilities and tools required to enable transformation into Industry 4.0 through integrated product and process design. Biedermann et al. (2016) stated that maintenance needs to change to meet the requirements of Industry 4.0 and emphasized the necessity of knowledge and data management for improving predictive maintenance performance. Diez et al. (2015) proposed a novel lean shop floor management system, namely the Hoshin Kanri Tree (HKT). The authors also noted that the standardization of communication patterns by HKT technology should bring significant benefits in value stream performance, speed of standardization, and learning rates to the Industry 4.0 generation of organizations.

The Proposed Methodology

First, some brief information about the basic concepts of lean philosophy and lean production systems will be presented. Lean philosophy primarily aims at the elimination of all activities that consume time and resources but do not add value to the physical completion of the products (Womack and Jones 2010). These activities are called waste, or *muda* in Japanese, and are termed as non-value adding activities. Here, the value is defined from the end customers' point of view and is product specific. Hence, a value-adding activity is one that contributes to the physical completion of the product and that the customer may want to pay for (Womack and Jones 2010). According to lean philosophy, the intention is to eliminate wastes. However, sometimes some of the wastes seem to be inevitable with the current technologies or manufacturing assets (Womack and Jones 2010). For instance, while switching from one product to another, a setup time can be unavoidable. Besides, there are other wastes that can be immediately eliminated by implementing lean tools and techniques.

According to lean philosophy, there are seven traditional wastes or non-value adding activities that are common within manufacturing systems. These are over-production, transportation, motion, waiting, inventory, unnecessary processing, and defective parts/products (Ohno 1988). Later, Womack and Jones proposed that products or services that do not meet the customer expectations should be regarded as a kind of waste (Womack and Jones 2010). Overproduction waste includes producing items for which there is no order or requirement (Liker 2004). This is the worst kind of waste, since it causes other wastes to occur. Due to overproduction, a large amount of inventory accumulates, an excess amount of staff is employed, excess storage space is occupied, and so on. Inventory waste is linked to overproduction and also includes excess raw material, work-in process, and finished goods inventory holding. Besides, excess inventory hides problems within the production system such as frequent machine breakdowns, long setup times, and defective parts.

There are several lean tools and techniques that can be utilized for waste elimination. The lean tools and techniques and the wastes that they help eliminate are shown in Table 2.

On the other hand, there exist various advanced Industry 4.0 technologies and cyber-physical systems that can be employed for waste elimination in advanced manufacturing systems. The most fundamental technologies and the associated waste types that these technologies help reduce are depicted in Table 3.

The methodology for implementing these technologies integrated with lean tools is discussed. Figure 1 illustrates this projected relationship between the lean tools and techniques and the advanced technologies. The figure is like a ladder, implying that the lean tools and techniques should be implemented in a sequential manner. First, the layout of the manufacturing system should be converted into a cellular manufacturing system that aims to produce product families through the use of autonomous and dedicated cells that are equipped with all required resources

Table 2 The seven wastes versus lean tools/techniques

	Cellular manufacturing	Setup reduction	Quality control	TPM	Production smoothing	Kanban	WIP reduction	Supplier development	Jidoka	CIM
Overproduction	√	√				√	√	√		
Transportation	√									
Motion	√								√	√
Waiting	√	√		√	√	√		√	√	√
Inventory	√	√	√		√	√	√	√		
Unnecessary processing		√								√
Defectives		√	√	√				√	√	√

Table 3 Seven wastes and advanced Industry 4.0 technologies

	Additive manufacturing (3-d printing)	Augmented reality	Simulation and virtualization	Adaptive robotics	IoT	Data Analytics	Cloud computing
Transportation		√	√	√		√	
Motion		√		√			√
Waiting	√		√	√	√	√	√
Inventory	√				√	√	
Unnecessary processing	√		√	√			√
Overproduction	√				√	√	
Defectives	√	√	√	√	√	√	

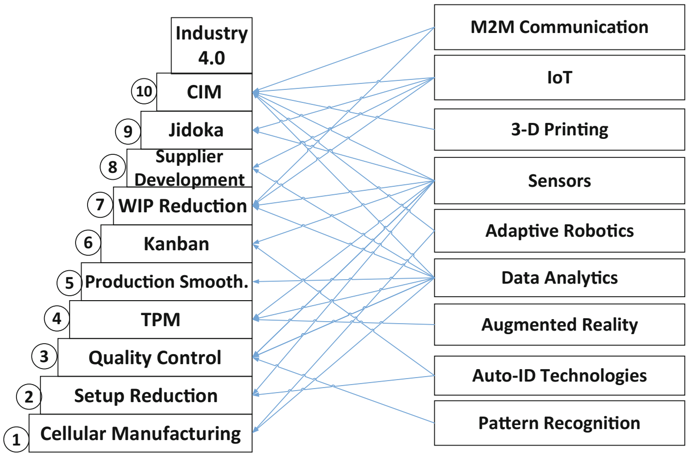

Fig. 1 Lean tools and Industry 4.0 technologies ladder

(Durmusoglu and Satoglu 2011). Besides, adaptive robotics can be employed for enhanced material handling and parts loading–unloading. For setup reduction purposes, sensors that detect the components of the machines such as dies, blades, and so on can speed up the internal setup operations and protect the operators from accidents. Besides, adaptive robotics can also be implemented for setup reduction.

Quality control and foolproof mechanisms (*poka yoke*) are other important aspects of lean production systems. To prevent the production of defective parts and products, pattern recognition augmented reality technologies and sensor applications can be utilized.

Total Productive Maintenance (TPM) aims to improve the overall equipment effectiveness of the machines, which includes reduction of time, speed, and quality losses (Ahuja and Khamba 2008). Augmented reality can be utilized to guide the operators in the performance of maintenance activities. Besides, sensors that keep track of vibration, noise, and heat help operators to detect abnormal conditions before failure.

Production smoothing is a production scheduling activity that aims to produce the same quantities of a part or product on a daily or hourly basis, as far as possible. Data analytics is a suitable tool for analyzing the demand frequency coming from customers.

Kanban is a lean production tool where pull-production control is performed. However, thanks to advanced auto-ID technologies, instead of scanning the barcodes of many kanbans, RFID tags are detected by readers and quick communication between the stages can be achieved.

Better M2M Communication, IoT, sensors and data analytics should be used to reduce Work-in Process (WIP) among machines. Besides, by means of data analytics, the cycle times and failure characteristics of the machines can be analyzed and the buffer area capacities among the machines can be adjusted.

For supplier development purposes, better data analytics should be employed for better analysis of demand data. To achieve better coordination and communication among the supplier and customer parties, IoT technologies should be employed.

Jidoka means automation with a human touch (Liker and Morgan 2006). In other words, the manufacturing system employs automation technologies under the supervision of the workers. So, while implementing *jidoka*, sensors and IoT can be employed.

While converting system into a computer-integrated manufacturing system, M2M communication, sensors, IoT, 3-D printing, adaptive robotics, and data analytics can be employed to obtain more benefit from the advanced manufacturing technologies.

Automation-Based Lean Production Applications

Industry 4.0 technologies and automation can be applied to several methods of lean production. The following section describes examples of possible combinations.

E-Kanban Systems. The digitalization of the kanban system has already been known for several years. Conventional, physical cards for an order-oriented production control are replaced by virtual kanban (Lage and Filho 2010). Depending on the implementation of this so called e-kanban system, missing or empty bins are recognized automatically via sensors.

Automation in Error-Proofing. Magna T.E.A.M. Systems makes widespread use of bar-coding technology to eliminate human error and production mistakes. Operators scan bar codes wrapped around their wrists to ensure that they are assembling the correct product on high-mix production lines. All operators use bar codes to log into their workstations so that there is a record of who is building what part. Electronic work instructions displayed at every workstation address error proofing and serve as a visual aid to operators (Weber 2016).

***Chaku Chaku* Lines**. In 2012, the University of South Denmark, together with the toy manufacturer Lego A/S, developed approaches for integrating automation technology in U-shaped assembly stations, also known as *chaku chaku* lines. In particular, human–machine interaction was the focus of this project. As a result, they developed a local order-management system that shifts typical tasks of ERP systems to employees on *chaku chaku* lines (Bilberg and Hadar 2012). Moreover, the ongoing research project "Lean Intelligent Assembly Automation" also addresses *chaku chaku* lines (Kolberg and Zühlke 2015).

iBin System. 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 wirelessly reports 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 in an order-oriented way (Würth Industrie Service GmbH & Co. KG 2013).

QR Code Integrated Milk-Run System. Wittenstein AG and BIBA—Bremer Institut für Produktion und Logistik GmbH, among others, are working on a flexible material supply system for production lines through the state-funded project "CyProS". Instead of using 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 realized by conventional tablet PCs (Kolberg and Zühlke 2015).

Pick-by-Vision. In the DHL application, warehouse workers see the physical reality of the aisles and racks in front of them just as they could if they were not wearing head-mounted displays, but this is augmented by a superimposed AR code in the form of a graphical work instruction, which appears after they scan the barcode at the storage location with their smart glasses. This code tells the workers where to go, how many items to pick, and even where to place them in their trolleys. When the pilot project is complete, DHL evaluates the operational suitability and economic feasibility of adopting augmented-reality vision picking. Meanwhile, its trends-research team has already identified other logistics activities that could be enhanced by a judicious dose of AR technology (Url-1).

Augmented Reality-Based Work Standardization. The project "MOON" (asseMbly Oriented authOring augmeNted reality) is being developed by Airbus Military. MOON uses 3D information from the industrial digital mock-up to generate assembly instructions and their deployment by applying augmented reality technology. A prototype was developed for the electrical harness routing in Frame 36 of the Airbus A400M (Servan et al. 2012).

Plug'n'Produce Workstations. Industry 4.0 could furthermore support lean production's requirement for a flexible, modular production. For several years, SmartFactoryKL has demonstrated modular workstations based on standardized physical and IT interfaces, which can be flexibly reconfigured to new production lines via Plug'n'Produce. According to the Single-Minute-Exchange-of-Die (SMED) principle, the setup time should be reduced to less than 10 min (Kolberg et al. 2016).

Automatic Mold-Change System: At K 2016 in Dusseldorf, Staubli of Germany (U.S. office in Duncan, S.C.) demonstrated complete hands-off mold changing in less than 2 min, and company spokespersons said the system could reduce that to 1 min. A mold table on rails carried a preheated mold into position beside the press. A sensor in the cart read the mold setup parameters from a chip in the mold. For the mold already in the press, all power and data connections were disconnected automatically within 3 s (Url-2).

Digitized *Heijunka*. Besides the flexible material supply system, Wittenstein AG digitized the Heijunka-Board. *Heijunka*, also known as levelling, describes a method for converting customer orders into smaller, recurring batches (Verein Deutscher Ingenieure e.V. 2013) (Kolberg et al. 2016).

Predictive Maintenance. Condition monitoring, data analytics, and early prediction of failures increase the uptime and overall equipment effectiveness (Bal and Satoglu 2014). For this purpose, predictive maintenance practices in manufacturing facilities have increased. In the oil and gas industry, where equipment is in remote locations, oil fields have been digitized by means of sensors. The name of the software platform is MAPR Distribution Including Hadoop® (MAPR 2015).

Conclusion

The approach used in this paper answers a significant part of this question and illustrates that lean manufacturing and Industry 4.0 are not mutually exclusive but can be seamlessly integrated with each other for successful production management. This paper analyzes the researches and publications concerned in the field of Industry 4.0 and identifies how they act as supporting factors for implementation of lean manufacturing.

Industry 4.0 will not solve the problems of mismanaged and weakly organized manufacturing systems. Its tools should be applied to lean activities that are performed successfully before automatization. In addition, effective information flow should be maintained effectively before introducing ICT. In this context, keeping the data in the correct and current manner is a critical success factor in both Industry 4.0 and lean production.

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