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Towards Lean Production in Industry 4.0

Beata Mrugalska*, Magdalena K. Wyrwicka

Poznan University of Technology, Faculty of Engineering Management, Strzelecka 11, 60-695 Poznan, Poland

Abstract

Lean Production is widely recognized and accepted in the industrial setting. It concerns the strict integration of humans in the manufacturing process, a continuous improvement and focus on value-adding activities by avoiding waste. However, a new paradigm called Industry 4.0 or the fourth industrial revolution has recently emerged in the manufacturing sector. It allows creating a smart network of machines, products, components, properties, individuals and ICT systems in the entire value chain to have an intelligent factory. So, now a question arises if, and how these two approaches can coexist and support each other.

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Keywords: industry 4.0; lean automation; lean production; production management

1. Introduction

Lean concerns a production system that is oriented on learning of organization through continuous improvements. It has its origins in the Toyota Production System and has been recognized as doing more with less. Therefore, it aims at reducing unnecessary variations and steps in the work process by the elimination of waste which is perceived as any action that does not add value to the product or services. Originally, it was focused on the elimination of such wastes as defects of requiring rework, unnecessary processing steps, movement of materials or people, waiting time, excess inventory, and overproduction. Nowadays, it covers diverse aspects of the manufacturing starting from the initial stage of product life cycle such as product development, procurement and manufacturing over to distribution [1]. It is implemented as a philosophy and a set of tools and practices to achieve the highest quality, lowest cost, and shortest lead time. It is an effect of a complex, pro-quality management in all areas of enterprise activities [2]. It can be also considered as an extended just-in-time including all parties involved in supply chain, intra and inter-

* Corresponding author. Tel.: +4-861-665-3364; fax: +4-861-665-3375.
E-mail address: beata.mrugalska@put.poznan.pl

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organization [3, 4]. Thus, it is a multi-dimensional approach that can work synergistically to create an efficient, high quality system to deliver products in accordance with the pace of customer demand with minimum waste [5, 6].

2. Lean Implementation

Generally, the successful implementation of any management practice often relies on organizational characteristics. However, it should be emphasizes that not all organizations can or even should implement the same set of practices. The most often revealed practices commonly associated with lean production are: bottleneck removal (production smoothing), cellular manufacturing, competitive benchmarking, continuous improvement programs, cross-functional work force, cycle time reductions, focused factory production, just-in-time/continuous flow production, lot size reductions, maintenance optimization, new process equipment/technologies, planning and scheduling strategies, preventive maintenance, process capability measurements, pull system/Kanban, quality management programs, quick changeover techniques, reengineered production process, safety improvement programs, self-directed work teams, total quality management [5]. However, it should be emphasized that these tools create a system so they contribute to the elimination of a particular type of waste and they should be applied together. The following approaches are often treated as "lean toolbox" [2].

As far as the implementation process of lean production is concerned there are discussed diverse frameworks. According to Ålström [7] it is evident that improvement activities appear in the sequence in manufacturing, however, continuous improvement should be introduced late during the process to allow it to benefit from the earlier established other principles. Storhagen [8] suggests that continuous improvement and change can be supported by job rotation and teamwork which only in the beginning of lean implementation allow taking the advantage.Moreover, it is suggested that employees' attitudes to quality should be changed to get material flow which contains only value adding operations [9]. Following Womack and Jones's "lean leap process" [1] there is a need to identify a change agent to create a new lean organization. Such person should be the first one who acquires lean knowledge to be able to share it with the rest of organization before mapping value streams. After creating a lean function and strategy, business systems should be fixed. Lean thinking can be recognized as completed when it is applied to suppliers and customers, a global strategy is developed, and continuous improvement programme is transitioned from a top-down to a bottom-up. Furthermore, Hobbs [10] proposed a step-by-step implementation of lean which hypothetically can reflect the five lean principles (Table 1).

Table 1. Lean steps and principles.

Step	Lean principle
Establish strategic vision	-
Identify and establish teams	-
Identify products	Value
Identify processes	Value stream
Review factory layout	Flow
Select appropriate pull strategy	Pull
Continuously improve	Perfection

Source: Author elaboration on the basis [1, 10].

It can be noticed that steps three to seven are linked to the five lean principles, whereas it is difficult to assign the original lean principles to steps one and two. Therefore, Hines [11] proposes to extend the classical principles to "people" and if it is added the second step can reflect it. Finally, the first step can be suggested to be a starting point for any strategic implementation project, and thus it can be considered as "a pre-step". An alternative approach was proposed by Bicheno and Holweg [12] who perceived the implementation of lean hierarchically as presented on Fig. 1.

Fig. 1. Hierarchical approach to lean implementation.
Source: Author elaboration on the basis [12].

This approach is established for a longer-term implementation, where the previous steps should be finalized before initiating the next ones.

Moreover, in the case of lean production the research studies carried out in manufacturing industries revealed that any organization is likely to adopt lean practices regardless its scale [13, 14]. Nevertheless, it is evident that either small or large business has its own benefits of lean implementation (Fig. 2).

SMALL BUSINESS

- ✓ Ease and speed of changing organizational culture
- ✓ Fast decision making
- ✓ Less layers of management
- ✓ High level of innovativeness
- ✓ Simple, clear, direct communication
- ✓ Close to customers, faster feedback and understanding and response to customers' needs
- ✓ Flexibility
- ✓ Easier implementation of multifunctional teams, quality circles, total productive maintenance
- ✓ Strong staff loyalty

LARGE BUSINESS

- ✓ Access to resources
- ✓ Experienced and/ or expert staff
- ✓ Experience in in-house lean or continuous improvement, understanding their potential benefits, processes, requirements and challenges
- ✓ Ease of making the commitment of human resources
- ✓ More likely to have metrics and data available
- ✓ Applicability of tools
- ✓ Opportunity for efficiency for not standardized processes
- ✓ Negotiating power over suppliers to develop a lean supply chain easier

Fig. 2. Advantages of small and large business in lean implementation.
Source: Author elaboration on the basis [13].

Generally, the characteristics of the organization, where lean production has been implemented, can be as follows [14]:

- team-work organization performed by operators who are flexible, multi-skilled and their responsibility for work within their areas is high
- active shopfloor problem-solving structures, central to kaizen or continuous improvement activities
- lean manufacturing operations, where problems are exposed and corrected by low inventories, quality management, prevention rather than detection and correction, small number of direct workers and small-batch, just in time production
- high commitment of human resource policies emphasizing a shared destiny within the organization
- closer relations with suppliers
- cross-functional development teams
- retailing and distribution channels liable for close links to customers.

3. Industry 4.0

The adoption of information and communications technology into manufacturing industry started in the 1970s. However, the main ideas of Industry 4.0 were published for the first time in 2011 [15]. In the same year it became a strategic initiative of the German government and was included in the "*High-Tech Strategy 2020 Action Plan*" [16]. Similar strategies have also been proposed in other industrial countries, e.g., on a European level, the corresponding catchword is "Factories of the Future","Industrial Internet" in USA and "Internet + " in China.

Despite of the great interest in the concept of Industrie 4.0 worldwide, there is no one formally respected definition for it. It is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes" [17], or "a new level of value chain organization and management across the lifecycle of products" [18] or "a collective term for technologies and concepts of value chain organization" [19]. Thus, the concept of Industry 4.0 can be perceived as a strategy for being competitive in the future. It is focused on the optimization of value chains due to autonomously controlled and dynamic production [20]. It covers the design and implementation of competitive products and services, the administrative powerful and flexible logistics and production systems" [21]. In order to achieve the increased automation the technological concepts of Cyber Physical Systems (CPS) can be used to work autonomously and interact with their production environment via microcontroller, actuators, sensors and a communication interface [22]. However, the introduction of both CSP and the Internet of Things, where things are supposed to initiate both a process of preparation, design, planning, optimization, tasks for tools, and human if necessary, is leading in a 4th Industrial Revolution referring to future (Table 2).

Table 2. Production evolution.

	Past	Present	Future
Communication system	analog	Internet and Intranet	Internet of Things Cyber Physics System
Concept	Neo-Taylorism	Lean Production	Smart Factory
Solution	Mechanization and automation	Automation and computerization	Virtualization and integration

Source: Author elaboration on the basis [23, 24].

CPS is similar to the Internet of Things as it shares the same basic architecture; however, it presents a higher combination and coordination between physical and computational elements [25].

The Industry 4.0 can be further described by three paradigms: the *Smart Product*, the *Smart Machine* and the *Augmented Operator*. The main idea of the *Smart Product* is to change the role of the work piece from a passive to an active part of the system. In such a system the products have a memory to store operational data and requirements individually, and are able to request for the required resources and coordinates the production processes for its completion [26]. In the paradigm of the *Smart Machine* a traditional production hierarchy is replaced by a decentralized self-organization which is realized by CPS [27]. In such a system open networks and semantic descriptions allow to communicate the autonomic components and local control intelligence communicates with other devices, production modules and products what makes the production line flexible and modular. It leads to the self-organization of machines within the production network, plug-and-play integration or even replacement of new manufacturing unities. Finally, the *Augmented Operator* addresses the automation of knowledge which makes it the most flexible and adaptive part in the production system [28]. Such a worker is supposed to be faced with a large variety of jobs such as specification, monitoring and verification of production strategies. In the same time he may manually interfere in the autonomously organized production system. He is provided the support by the mobile, context-sensitive user interfaces and user-focused assistance systems [29]. It allows him to fulfill the potential and be in the role of strategic decision-makers and flexible problem-solvers in the gradually growing technical complexity.

According to the results of a study "Industry 4.0" published by the Fraunhofer Institute, it is possible to indicate three future-relevant themes related to it such as: dealing with complexity, capacity for innovation and flexibility [30]. Moreover, it is possible to derive six design principles from its components: interoperability, virtualization, decentralization, real-time capability, service orientation and modularity. Interoperability ensures the connection and communication between physical components, humans and Smart Factories, whereas virtualization is realized as virtual copy of physical objects. Due to the decentralization and real-time capability the components are allowed to take decisions on their own on the basis of the collected and analyzed data in real time. The services of companies, CPS, and humans are provided by the Internet of Service and can be used by other contributors. The replacement or extension of particular modules assures a flexible adaptation of Smart Factories to the changing requirements [18, 31]. In order to realize these design principles, a dual strategy should be implied [31, 32]. The technologies, which have been already implemented, should be modified to fulfill the special requirements of manufacturing technology, research and development work in a new production location and market [33]. The attention should be paid to three types of integration: horizontal, vertical and end-to-end integration [33, 34]. Horizontal integration refers to a generation of value-creation networks involving integration of different agents such as business partners and clients, and business and cooperation models, whereas, vertical networking concerns smart production systems, e.g.: smart factories, smart products, the networking of smart logistics, production and marketing and services, with a strong needs-oriented [34]. End-to-end integration is targeted at gaining on product design, manufacturing and the customer [33]. However, according to Deloite [35] it is possible to differentiate four integrations, where the first two are the same, but they added two more such as through-engineering across the value chain and exponential technologies.

Even though complexity of Industrie 4.0 system is growing it has a huge potential which is as follows [33, 35]:

- specialized industry-specific solutions ("pull from the customer") and individualized understanding of customers' needs even in a case of manufacturing one-off items, having very low production volumes (batch size of 1) and still gaining a profit
- increase competitiveness and flexibility resulting from dynamic structure of business processes (i.e. quality, time, risk, robustness, price and eco-friendliness), adjustment to changes in demand or breakdowns in the value chain
- optimized decision making due to end-to-end visibility in real time
- increasing resource productivity (providing the highest output of products from a given volume of resources) and efficiency (using the lowest possible amount of resources to deliver a particular output)
- value opportunities (innovative services, new forms of employment, opportunities for SMEs and startups to develop B2B services)
- keeping productive workers for longer proving them diverse and flexible career paths
- work-life-balance
- high-wage economy with tied-up capital cost, cut energy costs and reduced personal cost.

4. Linking Lean Production and Industry 4.0 – case studies

4.1. Smart Product

In the reference to Kaizen, which helps to pave the way on lean journey, Smart Products can collect and use for analysis the information about repeating actions from their sensor and semantic technologies. They have unique properties such as: context-aware, adaptive, self-organized, and proactive and the ability to support the whole life-cycle which allows them for continuous improvement process. Moreover, their data allow for visualization of manufacturing process and flow of information for a chosen group of products. On this basis it is possible to create a Current State Map, which shows wastes in particular processes, and assign future strategic planning activities, what is the aim of Value Stream Mapping. Additionally, a Smart Product could contain Kanban information in order to control production processes what was already presented by *SmartFactory*^{KL} at Hannover Messe 2014 in Germany [36].

4.2. Smart Machine

A Smart Machine can contain a smart panel (e.g. Advan Panel [37]) which is based on RFID UHF. Such a solution enables to detect the tagged Kanban cards in real-time. It is assumed that a read-rate of cards placed on such a panel is typically 100%. Additionally, such panels can prevent detecting other tagged Kanban cards that are not placed on the panel, but which are at a close physical distance from the panel. Except RFID, the continuous improvement can be also assured due to production line data collected from machines with technologies such as actuators, sensors and wireless video. These data are analysed and proceeded in the cloud to give better operational intelligence but mainly to avoid mistakes what is the main idea of Poka Yoke. Furthermore, the application of Plug'n'Produce makes it also possible to introduce Single Minute Exchange of Die method into whole production lines.

4.3. Augmented Operator

The Augmented Operator should reduce the time between failure occurrence and failure notification. In order to achieve it the Andon method can be applied which is one of the principal elements of the Jidoka quality-control method recognized as a part of the Lean approach. It is realized by showing signal lights on an operator smart watch in close to real time. The information concerns both error messages and error locations. Such alerts may be recorded in a database and further studied as part of a continuous-improvement program. In addition, failures can be recognized with CPS equipped with proper sensors and automatically initiate fault-repair actions on other CPS.

5. Conclusion

Lean production successfully challenged the mass production practices to the production systems focused on good quality products aimed at customers' satisfaction, where everything that does not add value is concerned to be waste. It can be the answer to a great flexibility of production systems and processes realizing complex products and supply-chains. In order to achieve it, it is advisable to introduce IT integration of the production level with the planning level, customers and suppliers by CPS known as "Industry 4.0". In the presented paper the review of literature about lean production and Industry 4.0 was presented to show the possibility of linking these two approaches. The examples were provided for smart product, machine and augmented operator in reference to lean production principles. It enabled to indicate that these two approaches can support each other.

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