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Convergence and contradiction between Lean and Industry 4.0 for inventive design of smart production systems

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Abstract. Due to the globalization, we have witnessed the emergence of new challenges, driven by a sharp drop in industrial production costs and a great ability to produce high quality products at competitive prices. To cope with these growing challenges, Industry 4.0 were launched in 2011. This concept represents the digitalization of the industry, integrating resources into production: people, machines and processes. These networked resources can interact with each other. Industry 4.0 optimizes the production system. The plant becomes agile, with flexible production methods, reconfigurable tools, and more efficient.

Considering the Lean requirements during the early stages of production system design could facilitate the development of Industry 4.0.

This paper mainly focuses on both Lean and Industry 4.0 by considering their requirements during the early stages of production system design. In this study, we analyze the convergence and contradictions for the implementation of these two concepts.

Keywords: Industry 4.0, Lean, design process, production systems, contradiction.

1 Introduction

Industry 4.0 will be able to produce a customized product more quickly, while limiting costs, better use of resources and with new solutions to reduce the difficulty of work and increase human ability to operate there [1].

Recent studies on both the Lean and Industry 4.0 concepts have proven the possibility of linking these two approaches [27,28,29,30]. In addition, concrete examples of the combination of these two concepts have been mentioned in literatures.

Our study makes an analysis of convergences and contradictions for the implementation of these two concepts.

After the introduction, we present a state of the art on industry 4.0 and Lean, their definitions, their evolution, their principles and their appropriate technologies. The third section deals with previous studies related to their combination and the next section outlines our study. In the two last sections we discuss our proposition and make a conclusion.

2 Literature review

2.1 Industry 4.0

A production system represents all the resources (users, machines, methods and processes) whose synergy is organized to transform the raw material (or components) in order to create a product or a service [2]. One of the driving forces of the evolution of production is the evolution of customer demand over time.

To meet the challenges, the history of the industry has three major changes.

The evolution of technology is accelerated and recent technologies are emerging in all areas. It then became necessary to be used more and more in factories. A good integration of recent technology into industries can increase industry performance in terms of productivity and customer satisfaction. We talk about industry 4.0.

Under "Industry 4.0" we mean the beginning of the fourth industrial revolution after mechanization, industrialization and automation.

Innovation should be promoted in order to overcome future challenges in meeting market requirements. A production system should be efficient, flexible, reactive reconfigurable [3], that can quickly change its structure, and agile in terms of volume of production.

Therefore, flexibility is a basis of production systems in Industry 4.0 to realize individualization of products [4]. Industry 4.0 focuses on improving competitiveness by reducing costs and increasing the flexibility of decentralized production systems to deliver customized products, which is an advantage to satisfy customer markets [5]. Which implies a small lot sizes and a large number of varieties.

According to Yin [6], Industry 4.0 is grouped into three dimensions according to the customer demand:

1. Variety: Companies can introduce multiple models for each product.
2. Time: The delivery time requested by customer must be short.
3. Volume: Standard product and platform volumes can be high or medium

Industry 4.0 meets all these requirements; it is a term that was invented at the Hanover Fair in Germany in 2011 to describe how these technologies will revolutionize organizations. The Fourth Industrial Revolution creates a world in which virtual and physical manufacturing systems cooperate globally with each other in a flexible way. This allows for absolute product customization and the creation of new business models [7]. Industry 4.0 describes the integration of modern ICT information and communication technologies into production [8].

This is the vision of automated "intelligent" factories, in which operators, sproduction system, products and customers are connected in physical cyber systems [9]. In these technical systems networked computers and robots interact with the real world to connect physical objects.

Sung, [10] claims that the digitalization of the manufacturing sector is driven by four disturbances:

1. The huge increase in data.
2. The power of calculation and connectivity.

3. The emergence of analytic and intelligence capabilities and new forms of human-machine interaction such as tactile interfaces and augmented reality systems.
4. The improvements in the transfer of digital instructions to the physical world.

The current work allows to emerge several concepts and need to define the relations between them. (see Fig. 1).

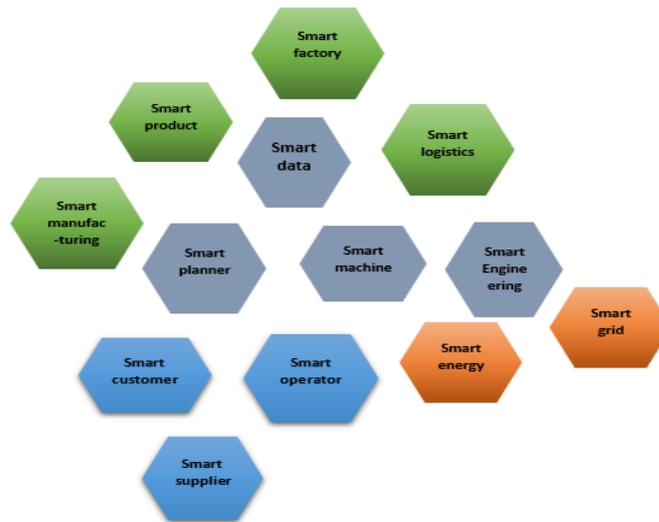


Fig. 1. Concepts of Industry 4.0. [11]

In the literature, the main components of Industry 4.0 are Cyber-Physical system (CPS), Internet of Things (IoT), Internet of Services (IoS) and Smart factory.

Through the Cyber-Physical systems (CPS), Industry 4.0 can react in an autonomous way, it is self-adaptable and agile. The use of such systems in production is then often described as Cyber Physical Production Systems (CPPS).

The Internet of Things (IoT) is an information network of physical objects (sensors, machines, ...) that allows devices to communicate and interact both and connect using standard technologies with centralized controllers [12]. The (IoT) involves the integration of both (CPS), which connect the physical and the virtual worlds, and the (IoT) into industrial processes. It also decentralizes analytics and decision making, enabling real-time responses [13].

In this environment, (CPS)s communicate and cooperate with each other and with humans in real-time and via the Internet of Services (IoS), that allows' service providers to offer their services via the Internet.

Based on (CPS) and (IoT), Smart Factory can be defined as a factory where (CPS) communicate over the (IoT) and assist users and machines in the execution of their tasks [14].

Hoffmann [15] illustrates that the smart factory is defined as follows:

- Products and services are flexibly connected via the internet.
- The digital connectivity enables an automated and self-optimized production of services.
- The value networks are decentralized.

Therefore, a Smart Factory contains technologies that provide the optimum methods and techniques for production system [16] (see Fig. 2).

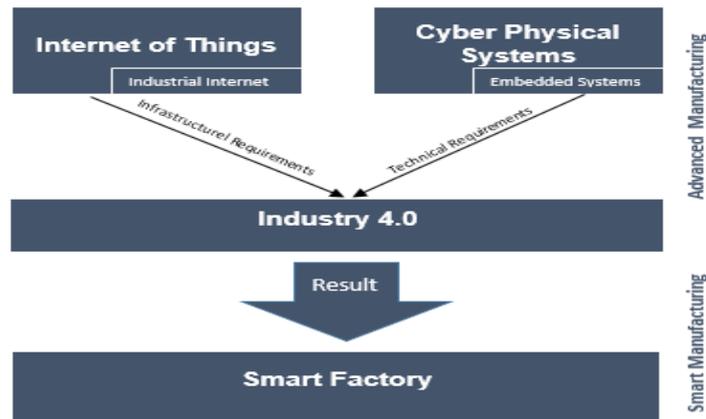


Fig. 2. Key terms in advanced manufacturing. [16]

In order to make this Smart Factory, industry 4.0 builds on six main principles. Moreover, these design principles make the factory autonomous, flexible and adaptable to a changing of the production system (see Fig. 3).

Interoperability is a characteristic of a production system in which its components are able to exchange information among themselves [17]. Smart Factory is virtualized in order to be able to simulate and follow in 3D products and production process. Decisions are decentralized via cyber-physical systems that can make decisions autonomous and in real time.

Recent advances in service-oriented computing and cloud computing including computational power, storage, and networking offer exciting opportunities for solving complex problems [18]. The Modularity lies in the plant's ability to adapt quickly to a changing demand, which increases the flexibility of production system.

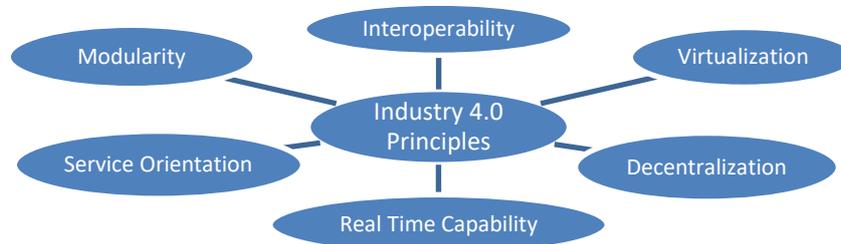


Fig. 3. Industry 4.0 Design Principles

In this environment, smart Factories need new technologies to enhance productive processes and to aim for value-adds to the concept of Industry 4.0.

To this moment, there are nine appropriate technologies and considering as the pillars of this concept. These technologies are integrated along these three dimensions:

1. The technical system: processes and tools.
2. The management system: organization, IT, performance management.
3. The people system: capabilities and behaviors.

To support the data needs in these smart factories, a Big data is necessary to integrate several layers and components for the collection, storage, processing, analysis and distribution of data [19]. With the use of cloud computing that enables to store Big Data, company will be more agile and flexible [20]. Virtual models of manufactured products are essential to bridge the gap between design and manufacturing [21], enabling simulation, testing and optimization in a virtual environment. Integration and agility in industrial automation need to improve to connect the company with the outside (suppliers and customers). Augmented Reality (AR) allows to give a virtual image in real time on all the information necessary for the operator, to help him perform these tasks in an optimal way. Thanks to mobiles and tablets, 3D glasses, other (AR) devices..., flow information, production monitoring, breakdowns, etc... are in the hands of operators in real time; enabling them to improve decision making, self-maintenance and quality. (AR) connects operators with each other and with their managers, quality teams, maintenance teams ...The future of manufacturing with 3D printing, which allows real objects to be created using a computer-aided design (CAD) tool are in the integration automation of the production processes with Additive Manufacturing technologies [22]. In order to enhance factory automation, sensors and software capabilities will make the new manufacturing equipment smarter [23].

In order to increase productivity, the new generation of robots are becoming autonomous, flexible and cooperative. they work side by side with humans do it for him the complex tasks, or by automating repetitive tasks in an ergonomic, user-friendly environment, while simultaneously ensuring the highest possible levels of security and safety.

2.2 Lean Production System

The Toyota Production System (TPS) is a concept developed by Toyota engineers to eliminate waste of the entire industrial process from design to distribution.

They have identified a seven forms of waste (Muda) [24]: by overproduction, waiting time, transport. Processing, storage, through movement and producing bad parts.

Lean's goal is customer satisfaction in terms of cost, quality and delivery time; which requires the optimization of production systems in its three dimensions (technical, management and users). In order to achieve the goals laid down, lean is based on five principles (see Fig. 4).

The first principle is to link the value principle to the customer. In principle, it means that everything that brings value to the customer is essential, but anything else is waste and must be eliminated. The second principle introduces the notion of flow. This notion

is crucial because it brings the visualization of the process, this makes it possible to visualize flows of materials and information and will facilitate waste identifications. Value Stream Mapping (VSM) provides an overview of activities, inputs, outputs and connections to detect wastes and plan their elimination. The elimination of waste allows for a continuous flow in a process where the operations are linked without disturbances and without interruptions. The Pull system is the technique of planning the production according to the customer's request, which makes it possible to reduce the stock. It is also about offering the customer a product whose added value is aligned according to their needs. The fifth and final fundamental principle is perfection, by examining and improving processes continuously. It is a process of permanent progress to bring new ideas and eliminate new wastes.

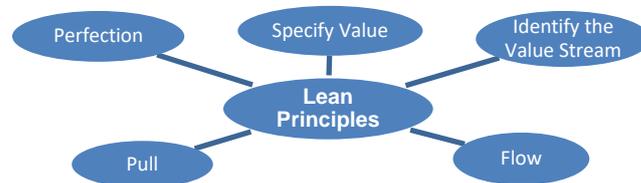


Fig. 4. Lean Principles

Lean relies on tools developed over several decades and proven methods. Lean means the application of various lean tools or techniques including value stream mapping (VSM), 5S, visual management, for cost reduction.

The famous Lean house contains Lean tools (see Fig. 5) [25]. The House contains (Jidoka) that is one of the two pillars of the Toyota Production System with Just in Time (JIT). (Jidoka) is introducing a culture of adapted systems that automatically detect deviations from normal operation. Thus, the necessary measures can be taken immediately to avoid the propagation of errors or machine breakdowns. The second pillar is Just in Time (JIT), it is the synchronization of the production process by using (Kanban), which are a signboard for the management of production via a pull system under a production with zero defects.

The main tools that are related to (Jidoka) are:

- Man machine Separation which allows operator to work on several machines at the same time.
- (Poka-yoke) which serves to improve the visibility of operators and limit these choices to perform a task in a way that the right choice is the only possible.
- (Andon) to alert operators in case of breakdown.

And the main tools that are related to Just in Time are:

- (Heijunka) is the smoothing of production.
- (Takt) time which allows to rhythm the production according to customer's demand.
- Pull flow according to customer demand which guarantees the variety of production.
- (SMED) (Single-Minute Exchange of Dies) is to reduce the changeover times less than 10 minutes, which increases the flexibility of the system.

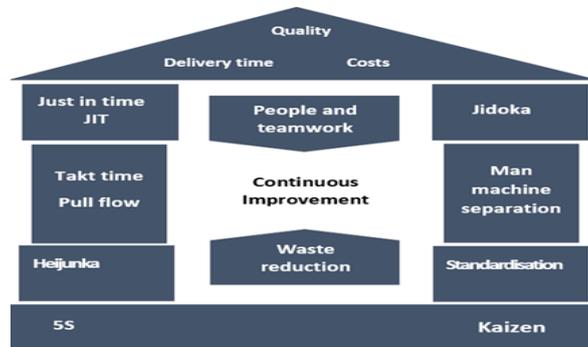


Fig. 5. Methods and tools proposed by Lean

In addition, to involve users in an orderly and organized environment, tools such as standardization serve to ensure the stability of the entire process and to facilitate the work of operators and reduce complexity. (5S) serves to increase the quality in the work area, based on lean thinking, all that is useless is to eliminate. Visual management is used to display information about the current status of production. Total Productive Maintenance (TPM) is used to achieve the highest possible plant performance the availability of production equipment in order to minimize maintenance costs.

The value stream serves to clarify and visualize the process including material flow and information flow for all the plant. In this way, the potential for improvement can be identified and the waste in the process can be reduced.

Therefore, lean's idea serves to create an organized environment in which the process is optimized, tasks are simplified and people are involved in order to reduce waste, increase performance and satisfy customer.

All these Lean tools could be integrated and taken into account from the early phases of the production systems design. This could lead to a more optimal production system from the beginning, which requires fewer improvements during the utilization.

Dekogel in [26] proposes a tool to integrate Lean philosophy into the design of new production systems. They consist of:

1. Describe the steps of the production systems design.
2. Illustrate the flow of different types of information during the design process.
3. Establish guidelines for taking Lean into account during design phase.

3 Convergence and contradiction between Lean & Industry 4.0

The elimination of waste requires new technologies. The combination of Lean and Industry 4.0 has already been mentioned in recent studies, and most of the Engineering Department of large international companies have developed a concrete solutions for a good implementation of Industry 4.0 in a manner consistent with principles and concepts of Lean on the improvement side of the plant through the integration of recent technology in the field of industry, and the consequent in terms of organization and the

human machine interaction, in order to satisfy the requirements of customer and to enhance the performance.

In this context, many questions may be raised:

- ✓ Are Lean and I4.0 compatible?
- ✓ Lean should it be combined with I4.0?
- ✓ Is industry I4.0 a contradiction of lean?
- ✓ Lean tools are they applicable in the concept of smart factory?
- ✓ Will we go towards complete automation?
- ✓ Where is the role of human in this environment?

Dombrowski (2017) [27] tries to answer some of these questions by asking 260 German industry with the aim of making a detailed analysis of the interdependencies between Lean and Industry 4.0. His study shows that the application of modern information and communication technologies (ICT) in Lean Manufacturing, can improve the performance of production systems by obtaining more efficient production and logistics processes.

Many concrete examples of such convergence to link Lean tools with the Industry 4.0 technologies have been mentioned in literature. Via sensors that makes the product intelligent and connects operator to products and machines, operator can be alerted in case of failure or defects by detecting the anomaly (self-maintenance). In addition, an electronic Kanban can be added to product, it contains the necessary information for the production which allows to receive the requirements of customers or suppliers in real time [28]. Accompanied by robots that works in an autonomous way next to human, add to that the technology of augmented reality, operator will be smart, he can obtain all the information on the process and product in real time. It is connected to the production systems and to the outside (customers, supplier). Andon systems are integrated to alert human in real time in case of malfunction. Even though the lean's philosophy that put people at the center of these objectives is preserved. The risk is that human missions may be limited to surveillance.

The smart machine is reconfigurable, flexible, able to work autonomously via the (RFID) technology, it can warn operator in real time in case of failure (Poka-yoke), it is possible also to reduce the changeover times (set up times) less than 10 minutes by using the Plug'n Produce technology, which increases the flexibility and reduce the unexpected stop [29]. Wagner (2017) [30] propose to develop a cyber-physic system, that replace the Kanban cards by a vertical integrated of machine to machine communication to link the all the flow information from the supplier between manufacturing order, machines to the customer, that guarantee the just in time delivery.

To more understand the convergence from examples in literatures, the table below is used to link lean tools combined with industry 4.0 technologies to obtain Smart concepts for successful implementation of both concepts in the of the new optimal production systems design. The ladder shows the possibility of linking these two concepts and that these can support each other (see Fig. 6). The connections were made according to concrete examples mentioned in the literature.

Lean I4.0	Poka-yoke	Andon	Heijunka	Man-Machine	Pull flow	SMED	VSM	5S	Standardisation	TPM	Visual Management	Kaizen
	Smart Product	1	1		1		1					1
	Smart Planner			1	1		1		1	1		1
	Smart Machine	1				1		1		1		
	Smart Operator	1	1	1	1		1	1	1		1	1

Fig. 6. Linking Lean to Industry 4.0

The table (see Fig. 7) illustrates the limits of the implementation of industry 4.0 and lean concepts, pointing out the convergences and contradictions according to different criteria, based on the three dimensions: human, process and organization. It derived from the views and examples mentioned in the literature, which was explicitly stated above in the state of the art.

The code "+" presents the effect of the implementation of Lean and Industry 4.0 on production systems according to criteria that influence the aspect of the production system and their ability to respond market requirements and the integration of recent technologies. "+" shows that there can be a low positive effect.

"++" shows that there can be a high effect.

"+++" shows that there can be the highest effect.

		I4.0	Lean	Convergence	Contradiction
Technical System	Applicability	+++	+		I4.0 is applicable In production systems design, while Lean is a continuous improvement on existing system.
	Productivity	+++	++	The digital connectivity enables an automated and self-optimized production	
	Flexibility	+++	++	Both increase the flexibility of production system	
	Agility	+++	+		I4.0 make the plant more agile then Lean
	Reconfigurability	+++	+		Lean does not propose more configuration
	Adaptability	+++	++	Smart factory is self-adaptable	
	Complexity	+++	+		I4.0 increases the complexity and Lean simplifies it
	Automation	+++	+		Risk of a lot of automaticity and a reduction of the role of the man

	Autonomous	+++	+		I4.0 can make decisions autonomously via the RFID technology
	Machine to Machine Interaction	+++	+		I4.0 interconnected machine without Human interaction
Management System	Standardization	+++	+++	is fundamental to guarantee interoperability	
	Auto maintenance	+++	+++	can react in an autonomous way to resolve problem	
	Zero Defect	++	++	Both promote the elimination of defect	
	Elimination of waste	+	+++		I4.0 does not propose a structured method
	Team Work collaboration	+++	+++	Both require connecting operators with each other.	
People System	Decision Making	+++	+		Cloud availability makes decision making easier
	Man-Machine Interaction	+++	+++	New robots work side by side with humans to help him to do complex tasks	
	Tasks	+	+++		Lean requires more simple task. Artificial intelligence may eliminate human tasks and reduce its role in monitoring operations.
	Operator autonomous	+++	++	(AR) devices put all information that they needs in the hands of operators in real time	

Fig. 7. Convergence and contradiction between Lean and Industry 4.0

4 Discussion

From examples mentioned in recent studies, lean and industry 4.0 can combine together to design an optimal and modern production system in a way of satisfaction of market requirements. The concept of Industry 4.0 covers all phases of system life cycle. In order to design more efficient production systems, it seeks to make smart not only the use of systems but also their logistics, their maintenance and their end of life. Nor would it be in contradiction with Lean principles in terms of customer satisfaction, reducing costs and eliminating waste with a view to designing an optimal production system. But the risk which we think they could be quite real nowadays engendered from making the mistake of full automation that limit the role of human and almost can be completely cancelled, which is one of the basic elements of Lean philosophy and which is all about it. In this paper, we analyze to what extent the two concept can be corresponded or clashed with each other within the process of design of production systems, following a several criteria listed above in the table. We see that I4.0 is applicable in production

systems design, while Lean is a continuous improvement on existing system. In addition, integrating I4.0 in the early design stage allows to develop a flexible production system, which can produce a variety of products without the need for major changes, more agile that adapts quickly to a changing demand, reconfigurable who can adjust quickly to adapt to new products. In contrast, Lean don't have a significant impact in regards to these criteria.

The complexity of system in I4.0 will be increased, accompanying by more automation that makes the system more autonomous. As we have previously stated, that's against the Lean principles which aims to simplify all tasks and procedures done by the system and its users. Lean is a set of methods and tools that can be applied on existing system, but I4.0 is a set of principles and objectives to consider in the design of new systems. Despite these some contradictions, the combination of the two concepts remains possible; That analyses should enable us to how to overcome these contradictions in order to integrate the two concepts Lean and Industry 4.0 in the early design stage of production system.

5 Conclusion and perspectives

Studying the convergences and contradictions of the implementation of Lean concepts and Industry 4.0 in production systems may strengthens the premise of considering the Lean and Industry 4.0 requirements during the early stages of production system design, which could facilitate the development of Industry 4.0. What is suggested was an overall approach aimed at a synergy between the two concepts Lean and Industry 4.0. And that could prove for future work to consider their requirements during the early stages of production system design.

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