Lean Manufacturing 4.0 - dynamic physical and cybernetic system for Industry 4.0

D-S Ionel¹, C Gh Opran² and B C Vălimareanu³
¹ University POLITEHNICA of Bucharest, Faculty of Engineering and Management of Technological Systems, 313 Splaiul Independentei, 060042, Bucharest, Romania, ² University POLITEHNICA of Bucharest, Faculty of Engineering and Management of Technological Systems, 313 Splaiul Independentei, 060042, Bucharest, Romania, ³ University POLITEHNICA of Bucharest, Faculty of Engineering and Management of Technological Systems, 313 Splaiul Independentei, 060042, Bucharest, Romania

E-mail: sorin.ionel@gmail.com

Abstract. The intelligent manufacturing system is realized through fusion between the production system with information and communication technologies. This allows to build a digital twin of physical production system, the two being connected and communicate each other data in real time about production status and progress. The existing Industry 4.0 physical system identify the active production resources, who are directly involved in the production processes, and of the passive ones, who have supporting roles. In Industry 4.0 those resources are directly interconnected with the corresponding cyber elements in order to supervise the whole system and the corresponding processes. Into this architecture, the physical production passive and active resources will form a dynamic subsystem, through which one can manage the physical and cybernetic changeable manufacturing processes and various products, in different manufacturing stages. This paper presents a solution to change the cyber-physical system by replacing the production physical active elements with those elements who need to change on the production line and the corresponding digital resources, including the specific Lean 4.0 production system tools who supervises the manufacturing cell and controls the execution. This dynamic system allows achieving a higher level of the production system.

1. Introduction

Industry 4.0 is an industrial concept who integrates analysis, planning, and operational solutions in the field of manufacturing automation, with the latest applications of digital manufacturing systems, such as resource virtualization, remote management, simulation, virtualization, augmented reality, with the latest technological advances of miniaturization.

The attractiveness of the Industry 4.0 concept is due to its real solutions for adopting latest technologies, and allowing advanced management and decision-making processes of complex production systems.

2. Industry 4.0

The production system evolution at the level of Industry 4.0 implies the interconnection of manufacturing system with the supply chain in a value-added network. The integration is done vertically (into the production systems) horizontally (between involved production systems) and in-depth (at value chain level). In order to achieve vertical integration, it is necessary to virtualize,
interconnect the subsystems, and to create an intelligent factory, which allows the production of customized products in small batches [1]. By horizontal integration, it allows obtaining a superior value between the organizations that are parts of the structure of the manufacturing system, following the entire life cycle of the product [2]. Integration at the own value chain level offers the possibility to design, realize, develop and recycle superior and intelligent products [3].

The Industry 4.0 integrative technologies are robotics, cyber-physical systems, additive manufacturing, cloud technologies, digitization, simulation, large databases, artificial intelligence, information technology and communications, RTLS and RFID, cyber security, sensors and actuators, mobile communications. Also, Industry 4.0 applies the principles of data management, interoperability, virtualization, decentralization, agile manufacturing, services orientation of manufacturing systems, and business process integration [3].

3. Smart manufacturing
The evolution of information and communication technology and production technologies has led to a new concept, known as smart manufacturing, through which the use of existing knowledge leads to new knowledge [4]. Adopting these technologies increases flexibility, reduces process variability and optimizes manufacturing planning processes, design and supervision of manufacturing execution. This level is known as Industry 4.0. According to this concept, virtual communications technologies (cloud and IoT) are involved in the control and intelligent management of manufacturing resources, which are virtualized and service-oriented, providing the necessary infrastructure for communication with the product, the user and the manufacturing system [5].

Within the production system, the associated products and services are connected, and the system environment allows the realization of a fully automated, digitized and self-configurable production, in which the value chain is presented in the form of a decentralized network, with autonomous components. The cyber-physical system supervise the processes of the smart factory, creates a virtual copy of the physical system who formulates decentralized decisions, communicates and cooperates in real-time with the physical system via IoT. Thus, it increases automatic processing capacity, different tasks execution, and machines can be allocated through the planning process, offering a flexible production solution, with simplified manufacturing processes [6].

4. Distribution of smart manufacturing processes
Diversified custom product ranges manufactured in small batches increase the complexity of production factors and process planning, such as the frequent change of the production line, supplementation of the labor force, delay of the activities, lack of machines, etc. Thus, there is a need for more flexibility to distribute production tasks, according to the available manufacturing capacities and capabilities [7].

The solution is process distribution planning, organized as a hierarchical structure, in two layers: supervision planning and operations planning. The planning level generates a generic process by analyzing product data, identifying processing characteristics, establishing orders and work sequences. The operational level transforms the generic plan into an execution plan, establishing specifications and processing parameters. Within this structure, function blocks have been introduced to ensure the portability and adaptability and reuse of the system [8].

5. Cyber-physical adaptive manufacturing
The Cyber-physical Systems (CPS) calculates and distributes processes in real-time and creates a secure production network. The CPS includes physical processes, software applications, computing platforms, and communication networks. The feedback loop includes sensors, actuators, computing systems, applications and communication networks. For implements CPS, it is necessary to adopt two technologies who allow monitoring and control of the physical subsystem. These are incorporated by function blocks and agents. Agents are autonomous components that have the ability to represent a physical or logical object in a system, it is able to act alone or interact with other agents to complete a
given task. The function block is a software application that incorporates algorithms and information necessary to perform a task at the logical controller [7].

Agents and function blocks give CPS the possibility to adopt a specific behavior for different events that occur at the physical production level. Function blocks and agents can identify an alternative route and adapt the processes. This prevents losses or prevents accidents [7].

6. Function blocks

Functions can incorporate and transfer a generic plan to be transformed into an operational execution plan. They become operable by integrating function blocks. This allows collaborative manufacturing through dynamic process distribution planning, remote monitoring and control, using an internet communication environment [8].

The basic function of a block is to generate an event as a result of applying the built-in set of algorithms, depending on the input variables. These blocks can be integrated into a network, each of them determining the common behavior whose result is assimilated to a composite function block, who can be connected to other composite function blocks resulting in composite function applications (figure 1) [7].

![Figure 1. Function block and composite function block [7].](image-url)

7. Lean manufacturing

In manufacturing systems, research is focused on reducing process variability, increasing productivity and developing new processing methods to reduce costs, implement predictive models, increase quality, adopt intelligent automation and robotics solutions by adopting lean manufacturing [9].

The Lean production system is built around the philosophy of increasing the performance of a production system using fewer resources, increasing efficiency, flexibility and profitability.

Lean manufacturing techniques offer concrete solutions to improve economic performance by identifying and eliminating waste, reducing inventory, increasing productivity and focusing on the quality and value desired by the customer [10].

The Lean principles underlying these performances are: identifying the value desired by the customer, identifying the processes and organizing the production flow by which this value is produced, organizing production at the customer's request, and continuously improving these processes. Activities and processes that do not provide value to the customer are defined as waste, and their sources are transport, waiting, overproduction, scrap, inventory, movement, and excessive processing. Lean manufacturing is an evolving concept who has developed many principles and tools.
Of these, the best known are Cellular Manufacturing, Setup Reduction, Quality Control, TPM, Production Leveling, Kanban, Work In Progress, Supplier Development and Jidoka. These tools are used differently depending on the particularity of the processes and their complexity [10].

8. Lean Production System 4.0

The Lean concept is seen as a solution to reduce automated production systems complexity. One of the latest developments of the adaptive production system is Lean Automation, which allows the system to adapt to future market requirements by achieving high flexibility and short flow information. This new theory offers the perspective of integrating the Industry 4.0 concept into a Lean production system [11]. According to Lean theory, there is a set of tools and applications through which waste is identified and eliminated or reduced. Also, a set of Industry 4.0 fundamental technologies has been identified through which losses are identified, managed, or eliminated (figure 2) [12].

![Figure 2. Waste management through Lean tools and Industry 4.0 technologies [12].](image)

The relationship between the Lean tools and Industry 4.0 technologies are presented in figure 3. The matrix logical organization is given by product transformation stages [12].

![Figure 3. The relationship between Lean tools and Industry 4.0 technologies [12].](image)
9. Lean to Lean 4.0 update
The transition from Lean to an adaptable, flexible and intelligent production system according to the Industry 4.0 concept, which is Lean 4.0, is possible by separating the production elements actively involved in the manufacture from the passive ones. The manufacturing system must allow the intelligent operation of the factory, which means to monitor the entire system and the corresponding processes, and the production of small batches, in which different production assets are involved, or raw materials, (according to the physical active assets), based on a common infrastructure (according to the physical passive resources). According to this architecture, the passive physical elements are interconnected with the corresponding cybernetic elements and provide to manufacturing management system information about the state, evolution, preventive maintenance needs. Physical active assets can be considered in a dynamic resource subsystem, through which physical and cybernetic manufacturing processes can be managed. This selection of digital technologies and services is needed to transform the flexible manufacturing cell into an intelligent manufacturing cell and accessing Lean manufacturing specific tools at the cyber system level to monitor processes. By introducing a technological layer as an interface for managing active manufacturing resources (necessary for a certain type of production) the cyber-physical system becomes adaptable and flexible on both dimensions. The connection of the cybernetic system to the physical production system through the function blocks allows the smart management of manufacturing cell (figure 4) [13].

Figure 4. Dynamic Resources Layer [13].

Within the intelligent manufacturing system, the dynamic manufacturing resources layer is positioned between the physical and the cyber system, it consists of these elements and individualizes each stage of the production process. Thus, on a production line, there can be Product D in the prepreg stage, Product C in the processing stage, Product B in the finalization stage, and Product A in the quality evaluation stage. Each of these production sub-processes corresponds to a dynamic layer corresponding to the physical and cyber resources involved in the production or pending the dynamic layers corresponding to the production of the following product (figure5) [13].

In this way, the manufacturing cell is transformed into an adaptable Lean-Industry 4.0 manufacturing cell by updating specific active components, and at the cybernetic level - by initializing
the corresponding digital elements, planning the production processes, as well as activation of Lean 4.0 tools for supervising the performance evolution of manufacturing cell (figure 6).

![Figure 5. Dynamic Production System [13].](image)

As a result, the cybernetic system is updated through continuous data and information, collected through physical system, and Lean 4.0 tools monitor the manufacturing cell processes, commands the execution of production, or intervenes by generating events at function blocks level [13].

![Figure 6. Lean-Industry 4.0 manufacturing cell [13].](image)
10. Industry 4.0 upgrading to Lean 4.0
Cyber-physical systems can be interconnected and can use the information provided by other elements associated with the production system. It also provides information about its own characteristics (status, objectives, operations or status), about the product, processes, and production capabilities. The components of the production system will be defined and included in the cyber-physical system through an application called the Asset Administration Shell (AAS) [14]. This is a digital, standardized representation of a production system physical or logical object that underlies the interoperability of the management applications included in the system. AAS includes the administration label, the represented object, different digital models of the object (submodels) and technical functionality description [15]. The AAS outline consists of header and body (figure 7). The header is standardized and contains communication instructions and information for managing subcomponents. The body of the AAS is structured in modules, which may include data, applications, or other reference components. [14].

![Figure 7. Asset Administration Shell outline [14].](image)

These modules are designed as manageable digital object memory units with standardized information. Can integrate applications developed to improve the management capabilities of the cyber-physical system by including complex computational functions, simulation, or codes for calling information stored in large databases. Each memory unit has an identifier and an content index, in order to quickly access the reference information or include new task modules. Organizing modules into blocks allows both local and remote data storage (figure 8) [14].

![Figure 8. Advanced Asset Administration Shell [14].](image)
The AAS functionality section is a platform for applications dedicated to improving CPS capabilities. The information included in AAS is standardized and refers to components properties, operating conditions, the manufacturing situation, describes relations between components and allocated resources. Thus, CPS defines production modules, infrastructure and product intelligent elements, all of them organized in a coherent and standardized digital structure [15].

The digital definition of elements, structures, equipment, processes is done by asset management shell (AAS), ensuring the identity, uniqueness and distinction, both within the production system structure and as a possible state in a future structure required by a particular manufacturing context. The sum of ASAs forms the cybernetic production system. The digital feature of AAS can include applications, codes or routines, which allow additional instructions to be run or can be nested in an AAS system with high complexity [14].

By construction, AAS allows the realization of an adaptable digital technological production system (Lean-Industry 4.0 System), able to supervise the processes both of physical and cyber manufacturing systems, the execution of production stages, and to make corrections by generating events. This adaptive digital production system is positioned within the cyber-physical system in a coordinating position, taking over the information provided by the cyber system in order to apply lean principles, monitoring flows and processes and to measure performance. Technically, for each Lean tool, applicable to the cyber-physical production processes, a digital Lean Asset Administration Shell (LTAAS) is defined, in the form of an application that will include codes and routines for analysis, evaluation and response for the supervised production stage, which is connected to the corresponding ASA defined at the cybernetic level of the production system. The communication will be performed and managed by the instructions included in the headers of both AAS and LTAAS, and the LTAAS will evaluate the set of information on status or evolution according to the defined functions (figure 9).

![Figure 9. Defining Lean Tools Asset Administration Shells.](image-url)
LTAAS instruments will be grouped and managed at the level of a meta-LAAS (MLAAS), defined by the manufacturing situation required by the production system and which will assess the evolution, determine and transmit in real-time to the cyber system the adjustment commands, for interpretation and application to the physical system through the function blocks.

The MLAAS can be defined to manage the entire production system, through cyber-physical systems in which it is included, to optimize, increase flexibility and adaptability, by initializing the corresponding digital elements, production process planning, as well as the activation of LTAAS for supervising the manufacturing system performance. Thus, the application of Lean principles and the integration of Lean 4.0 tools at the cyber-physical level of the production system allows intelligent, self-managing, and self-optimizing manufacturing (figure 10).

Figure 10. Implementing Lean 4.0 at Cyber-Physical Production System level.

Figure 9 and figure 10 are the original contributions of the authors.

11. Conclusions
The original and novel elements of the paper are the proposed solutions for the digital definition of Lean instruments at the level of the cyber-physical system and their integration in a cybernetic management structure through which the lean manufacturing principles can be applied.
By creating advanced Asset Administration Shells for each applicable Lean tool to the Industry 4.0 production system and integrating them into the cyber subsystem structure, a higher level of the organization of the production system is achieved. This results in a dynamic architecture that allows efficient management of physical and digital resources, gained from the superior advantages offered by Lean theoretical support and practices.

Including Lean Administration Shells in a digital meta-structure capable of managing the entire cyber-physical production system offers the possibility of integrating and applying Lean principles both at the level of each manufacturing stage and at the entire Industry 4.0 production system.

12. References

[1] Salkin C, Oner M, Ustundag A and Cevikcan E 2018 *Industry 4.0: Managing The Digital Transformation* (Switzerland: Springer International Publishing) chapter 1 pp 3-23

[2] Kagermann H, Wahlster W and Helbig J 2013 Recommendations for implementing the strategic initiative INDUSTRIE 4.0 [online] National Academy of Science and Engineering Accessed May 30, 2019, www.acatech.de, https://www.acatech.de/wp-content/uploads/2018/03/Final_report_Industrie_4.0_accessible.pdf

[3] Wang L and Wangb G 2016 Big Data in Cyber-Physical Systems, Digital Manufacturing and Industry 4.0 *IEEE Transactions on Automation and Manufacturing* 4 1-8

[4] Ioan Dumitrache I and Caramihai S 2010 Intelligent manufacturing: a new paradigm *IFAC Proceedings Volumes* 43 (22) pp 1-7

[5] Tao F, Zuo Y, Xu L D and Zhang L 2014 IoT-Based Intelligent Perception and Access of Manufacturing Resource Toward Cloud Manufacturing *IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS* 10 (2) 1547-1557

[6] Djassemi M 2008 Emergence of Multitasking Machining Systems: Applications and Best Selection Practices *Journal of Manufacturing Technology Management* 20 (1) 130-142

[7] Wang L and Wang X V 2018 *Cloud-Based Cyber-Physical Systems in Manufacturing* (Switzerland: Springer International Publishing)

[8] Wang L, Feng H-Y and Cai N 2003 Architecture Design for Distributed Process Planning *Journal of Manufacturing Systems* 22 (2) 99-115

[9] Sherwood J A, Dignam J J, Dobbins T and Boeman R G 2017 U.S. Composites Manufacturing Industry Technical Roadmap *Facilitating Industry by Engineering, Roadmapping and Science (FIBERS) Consortium* Accessed July 30, 2019, www.uml.edu, https://www.uml.edu/docs/FIBERS%20Composites%20Manufacturing%20Roadmapping%20Report_Published-31Aug2017_tcm18-286787.pdf

[10] Womack J P, and Jones D T 2003 *Lean Thinking* (New York: Free Press)

[11] Kolberg D and Zühlke D 2015 Lean Automation enabled by Industry 4.0 Technologies *IFAC-PapersOnLine* 48-3 pp 1870–1875

[12] Satoglu S, Ustundag A, Cevikcan E and Durmusoglu M B 2018 *Industry 4.0: Managing The Digital Transformation* (Switzerland: Springer International Publishing) chapter 3 pp 43-59

[13] Ionel D S, Opran C and Lamanna G 2020 Lean Manufacturing 4.0 of Polymeric Injection Molding Products. *Wiley Online Library. Macromol. Symp.* 389, 1900109 International Conference on Design and Technologies for Polymeric and Composite Products - POLCOM 2019

[14] Tantik E and Anderl R 2017 Potentials of the Asset Administration Shell of Industrie 4.0 for Service-Oriented Business Models *Procedia CIRP* 64 pp 363-368

[15] Barnstedt E et al 2019 Specification. Details of the Asset Administration Shell Federal Ministry for Economic Affairs and Energy (BMWi) Accessed July 30, 2019, www.plattform-i40.de, https://www.plattform-i40.de/Pl40/Redaktion/EN/Downloads/Publikation/2018-details-of-the-asset-administration-shell.pdf?__blob=publicationFile&v=5