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Lean-based management in process improvement projects in Industry 4.0

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Abstract
Digital transformation has generated major changes in the structure of production and numerous opportunities for development in today's industrial environment. For firms interested in optimizing their production systems and remaining competitive, the challenge is in adapting current production organization systems to the new requirements imposed by Industry 4.0. The new Industry 4.0 technologies and the well-known tools of Lean are essential in the manufacturing sector and other modern industrial organizations, their common goal being to enhance industrial performance and competitiveness. Through the analysis of current concepts and practices, as well as specialized literature in the field, this research is focused on developing a Lean 4.0 integration framework and assessing its impact on advanced production systems. Responses to several questions regarding the coexistence of the two approaches have been pursued to identify the potential of Lean and highlight the benefits in the current industrial context. Following an analysed case study, Lean implementation solutions in Industry 4.0 are proposed. This way, a development environment can be created those benefits from both traditional principles of efficiency and waste elimination in value creation chains and the advantages of implementing current digital technologies.

Keywords
lean management, Industry 4.0, production systems

1. Introduction

The challenge of the current era, dominated by digitalization – the concepts and Industry 4.0 technologies, although not entirely new, are "highly diverse, encompassing over 30 different technological fields" [1]. Thus, various problems arise, ranging from the standardization of concepts and terminology to the implementation and optimization of solutions. Interest in Industry 4.0 has rapidly increased in both academia and business, attracting researchers and companies through opportunities and investments.

Flexible production enables manufacturing systems to rapidly adjust to market dynamics and diverse customer demands, thus becoming a key driver of competitiveness. Today, the transition from Industry 4.0 – where some companies are already using new technologies – is moving towards a sustainable model of development – Society 5.0, as well as the development of digital production systems [2]. Designing production systems with the capability for rapid responsiveness to customer demands and deliver a wide variety of products is becoming an important competitive advantage for any company. Digital production, to which elements of artificial intelligence and new methods of Lean production can be added, constitutes the foundation for development in the current context of industrial evolution [3]. While Industry 4.0, considered contemporary but relatively new, has brought about major transformations in technology, existing Lean Management (LM) tools have proven their effectiveness over a long and stable period, being predominantly implemented in recent decades. One of the early analyses in the field (Sanders et al., 2016) [4] notes that although there were individual and scattered researches on Lean techniques at that time, and Industry 4.0 was in an initial phase of application, the potential for the integration of the two not being identified. In the following years, 2018-2023, with the increasing application of I4.0 principles, especially in production where Lean was already implemented, there was an increasing interest in the integration of the two "production paradigm". This is considering that their implementation can enhance the productivity, efficiency, and quality of mass-customized products demanded by customers.

The first hypotheses are formulated as the basis for potential models of integrating I4.0 with Lean Manufacturing and vice versa [5,6]. The authors of the scientific paper [7] perform a specific analysis using the Delphi study method, demonstrating, in their own perspective, a "one-to-one parity" between the elements of the two production paradigms. To examine the application of specific I4.0 technology for manufacturing environments that implement Lean management, research studies [8, 9] conduct a comprehensive literature review, emphasizing the multiple benefits for companies, such as improved operational efficiency, increased productivity, and enhanced competitiveness. Reviewing the published studies, predominantly in the last period, it can be considered that the analyses and research results published in specialized articles, which address the Lean - Industry 4.0 correlation, have not yet reached a standardization of the ideas and methods presented. Most often, these methods are described only empirically, with few developed specific case studies in which they can be integrated. The conclusion that emerges is that research can be expanded, especially in aligning existing ideas and providing a methodological support useful for companies to develop in a sustainable industrial environment, reaping the greatest benefits.

This scientific article contributes to the research field of engineering and production management, aiming to evaluate the opportunity of integrating Lean in the current industrial environment and its subsequent development. Structured into five sections, it starts by outlining the present state of advanced manufacturing system development and reviewing specialized literature regarding Lean Manufacturing and Industry 4.0 principles, emphasizing their advantages (Section 2). The proposed framework for the development of Lean 4.0 is detailed in Section 3, followed by a practical application in a case study, a Lean improvement project (Section 4). In conclusion (Section 5), the article presents findings and future research directions, towards the implementation of Lean 4.0 solutions.

2. Materials and Methods

2.1. Methodology

The working methodology aligns with the formulated hypotheses and seeks to address inquiries about the feasibility and alignment of the Lean approach with Industry 4.0. Within this research framework, solutions are sought for the working hypotheses, focusing on:

H1. The effective adaptation of Lean techniques with Industry 4.0 technologies;
H2. The benefits of I4.0 technology on optimizing Lean production, and vice versa;
H3. The potential for Lean 4.0 transformation in parallel with the progress of I4.0 digitization.

The analysis relies on current studies and research conducted within both the academic environment and the industrial sector. The present methodology takes into account the research objectives:

- Analyzing the current development context of the industrial environment and presenting the latest research in the area Lean & Industry 4.0, covering principles, key elements, techniques, and tools, implementation conditions, and their synergy;
- Assessing the opportunity of the Lean 4.0 system and proposing improvement solutions through a case study of flexible manufacturing;
- Drawing main conclusions and identifying future research directions.

2.2. Actual Trends in the Advancement of Production Systems

The current environment for the development of the European industry and new production systems is aligned with the requirements outlined in the New Development Strategy for Europe [10], focusing on key domains: modeling a globally competitive industry, the digital transition of the industry, and fostering industries that promote climate neutrality.

The shift toward digitalization in the industrial sector represents a priority area for creating a competitive industry within an integrated and technology-driven single market, with implications for the development of new professions and a new society. Current production systems are focused on implementing advanced technologies and adopting innovative business and management models and methods. This direction not only optimizes production processes and operational efficiency but also opens up new opportunities to be part of the emerging framework of Industry 5.0. This transition represents not only a technical advancement but also a shift in the way manufacturing systems engage

with the surrounding economic and societal context, fostering greater connectivity and flexibility. In the endeavor of a successful and sustainable digital transformation initiative, a series of challenges must be considered, arising from the current socio-economic environment in which companies, SMEs, and other organizations operate.

2.2.1. Approaches regarding Industry 4.0

Currently, through highly developed technologies, Industry 4.0 is bringing real changes through the digitization and connectivity of systems, and the integration of artificial intelligence elements. Industry 4.0 technological advancements are built upon several key pillars, including IoT–Internet of Things, BGA–Big Data Analytics, CC–Cloud Computing, AI–Artificial Intelligence, CPS–Cyber-Physical Systems, IPS–Intelligent Production Systems, R–Robotics, and HMI–Human-Machine Interface [3]. The analysis regarding the Industry 4.0 approach in the current specialized literature is synthetically presented in Table 1.

Table 1. The Industry 4.0 development framework – summary of reviewed papers [3]

Research Area	**Literature review**
Initiative I4.0 Concept	Ulrich S. (2013) [11]; Bauernhansel T. (2014) [12];
Industry 4.0 Technologies	Gupta B.B., et al. (2021) [13]; Culot G., et al. (2020) [14]
Basic Conceptual Models in I4.0 Industry 4.0	Dombrovski (2018) [6]; Sony (2018) [5]; Schumacher A. (2019) [15]; Amaral A. (2021) [16]
Sustainable Development through Industry 4.0	Ghobakhloo M. (2020) [2]; Leong W.D., et al. (2020) [17]
Supply Chain Management and Industry 4.0	Hahn G.J., et al. (2020) [18]; Ivanov D., et al. [19]; Sharma M., et al. (2023) [20]
Implementation of Industry 4.0 in Companies and SMEs	Vrchota J., et al. (2019) [21]; Veile J.W., et al. (2020) [22]; Lodgaard E., et al. (2022) [23]
The Impact of Implementing Industry 4.0	Zheng T., et al. (2020) [24]; Borowicz A. (2021) [25]; Pereira A.G., et al. (2020) [26]; Vinodh S., et al. (2020) [27]
Future Research Directions	Adel A. (2022) [28]; Prassida G.F. (2022) [29]; Li C., et al. (2023) [30]

2.2.2 Approaches to Lean Management

Developed as early as the 1950s by Taiichi Ohno, the Lean concept was first applied in the Toyota Production System (TPS) [31]. The TPS, a socio-technical system was integrated and developed to efficiently organize production and logistics, including interactions with suppliers and customers, with the goal of minimizing costs and waste. Womack & Jones [32] who regarded this management type as "an antidote to waste – any human activity that does not add value", further developed the Lean philosophy in the West. Social transformations have directly influenced industrial development and the evolution of production systems.

The Lean concept has the main task of identifying and reducing waste. The main types of inefficiencies recognized in the TPS – Muda-type losses, later applied in various companies, are overproduction, unnecessary transportation, waiting delays, reprocessing, stocks, over-processing, and unnecessary movements. All unnecessary tasks that waste time, resources, or space should be eliminated by utilizing Lean practices and instruments. By implementing the Lean concept, the goal is to achieve a continuous flow without bottlenecks and interruptions, without stocks in the flow, considering that production is oriented in the direction of the flow.

From its inception to the present, Lean principles have been applied across multiple domains, including manufacturing as well as areas like healthcare, tourism and hospitality, food industry, construction, etc. The analysis of the Lean management development framework in current specialized literature is synthetically presented in Table 2.

2.2.3. Opportunity for Lean 4.0 implementation

The implementation of Lean 4.0 in industrial companies involves an analysis conducted by management and the project implementation team, focusing on the internal environment and industry-

specific factors. Numerous organizations that have initiated the implementation process consider it beneficial to strengthen sustainable systems by incorporating an additional Lean aspect. The objective is to optimize products and services while enhancing market competitiveness, in response to shorter product lifespans and the growing trend of mass personalization to meet customer demands.

Table 2. The current stage in Lean development– summary of reviewed papers

Research Area	Literature review
Concepts - Lean Initiative Toyota Production System (TPS) Lean Thinking	Taiichi Ohno (1988) [31]; Womack et al. (1990) [32]; Jackson T. & Jones K. (1996) [33]; Rother M. & Shook J. (2003) [34]
Lean Techniques and Tools VSM; 5S Method; Standardized Work;	Jiménez M., et al. (2021) [35]; Lagarda-Leyva E.A. (2021) [36]; Noto G. (2021) [37]
Lean Methodologies and Applicability Production; Healthcare; Tourism Industry;	Akmal A., et al. (2021) [38]; Fiorillo A., et al. (2020) [39]; Domínguez R.A., et al. (2021) [40]
Lean Improvements System performance; continuous improvement	Massaaki I. (2013) [41]; Costa F. (2019) [42]
Lean Management & Sustainable Development Lean & Green & Sustainability Lean Management & Quality Management	De Giovanni P., et al. (2021) [43]; Abualfaraa W. (2020) [44]; McDermott O., et al. (2023) [45]
Lean Management & Innovation Lean Startup; Lean & Process Innovation	Rise E. (2013) [46]; Moldner A.K. (2020) [47]; Solaimani S., et al. (2019) [48]

The efficiency of systems, innovation, and processes can benefit from the combination of the two. The opportunity for implementing this framework is demonstrated by the potential for optimizing manufacturing and eliminating waste through the application of new management methods, automation techniques, followed by digitization and connectivity of production systems, specific elements of Industry 4.0 technology. Some possible common directions for production efficiency and optimization in the companies adapting their production and management tools have been analyzed (Table 3).

Table 3. The current stage in Lean development [3]

Lean Manufacturing 4.0	Industry 4.0 Technologies
Improved Production. Creating the Automated Value Stream: VSM 4.0; KANBAN 4.0; JIT 4.0	Cyber-Physical Systems (CPS)
Waste Reduction	Cloud Manufacturing
Industrial Internet of Things (IIoT) in Lean Environments	Internet of Things (IoT)
Improving Lean Data Analysis	Big Data Analysis
Virtualization of Lean Techniques and Tools	Virtual Reality & Augmented Reality
Lean in Flexible Manufacturing Systems	Autonomous and Collaborative Robotics
Digitalized: Jidoka, Poka-Yoke, VSM, KANBAN	Smart Machines; Artificial Intelligence (AI)
Lean Layout, One-Pice-Flow, VSM, JIT, KAIZEN, TPM	Process simulation; Digital Twin

3. Lean Improvement Proposals in I4.0. A Case Study

The present analysis is carried out within a furniture manufacturing enterprise. Considering the company's post-COVID development, a project to increase production capacity was initiated in response to management requirements. By applying Lean tools, the process was analyzed, critical points in the system were identified, and proposed solutions for implementing improvements were outlined.

3.1. Case Study Input Data

Stage I. Problem Formulation: "What problem are you trying to solve?": Insufficient production capacity; High stocks available in certain locations;

Stage II. Project Planning (Figure 1): *Objective:* Increase production capacity.

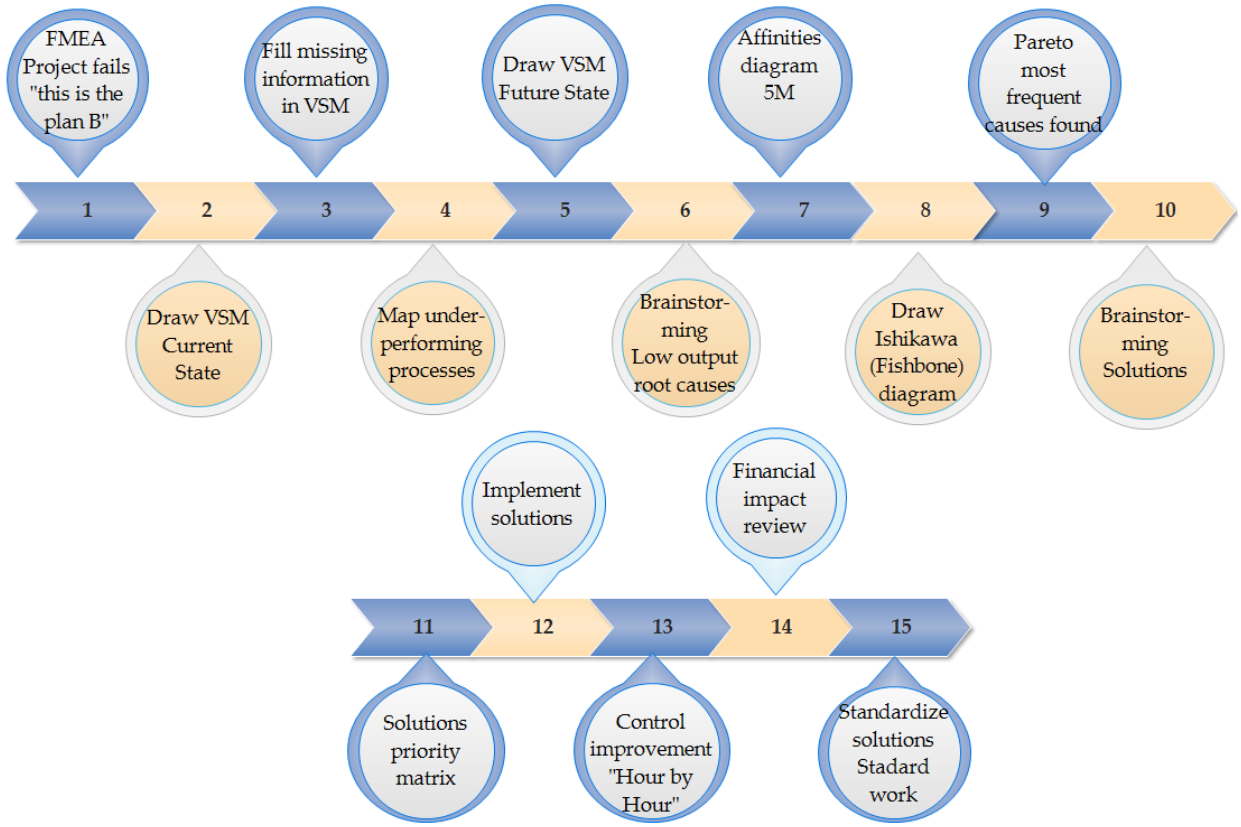

Fig. 1. Project implementation stages

3.2 Improvement Solutions

The analyzed production system encompasses several manufacturing lines (Line A – solid wood manufacturing; B – panel and veneer manufacturing; C – door manufacturing; D – drawers and shelves manufacturing; E – automatic manufacturing of doors) dedicated to furniture components and the standard assembly line. The production process involves distinct woodworking operations: cutting – straightening – planning – sawing – milling – turning – finishing – lacquering – assembly.

In a first stage, the Fishbone analysis was carried out, a useful tool in identifying the problems and drawing the Ishikawa diagram to identify the root causes. In each category 4 M (Man, Machine, Methods, Medium) the specific factors that could lead to the problems were identified. Once all the root causes were identified, together with the sub-causes, the project team performed the analysis and were able to prioritize them, according to their relevance and impact on the problem, resulting in the Pareto Diagram.

Following the study and mapping of the current VSM, the future VSM scheme was developed (Figure 2) and improvement and implementation solutions were proposed for each category of causes. In the context of the analysis conducted, technical measures are proposed for improving the production process: reducing transport times between operations by 15% through technical and organizational measures; optimizing changeover times (C/O) when changing the reference, by a 30% reduction, following the SMED (Single Minute Exchange of Die) workshop analysis; reducing downtime and equipment repair time through preventive maintenance solutions (new concept of Virtual Commissioning in I4.0); Cycle time (CT) reduction through the technological process optimization: proposing the implementation of automation on the assembly line and solution for implementing collaborative robots (HMI – Human Machine Interface).

Some proposed improvement solutions, which open new research directions regarding Lean 4.0 implementation:

Implementation of the shop floor management concept. It is achieved by tracking key indicators directly in production (quality, delivery, costs, safety): productivity, production achieved, throughput time, rejects, delivery performance.

Implementation of the changeover-wheel, a production management tool, the changeover-wheel, for equipment shared among multiple lines. This process can be optimized through new technologies application, increasing flexibility and responsiveness to changes in the production environment.

Implementation of the Andon 4.0 System to streamline interventions at machines during unplanned downtimes. A solution has been proposed involving the implementation of the Andon 4.0 system, which will integrate advanced IoT technology and Big Data analytics to enhance efficiency and performance of the analyzed production line.

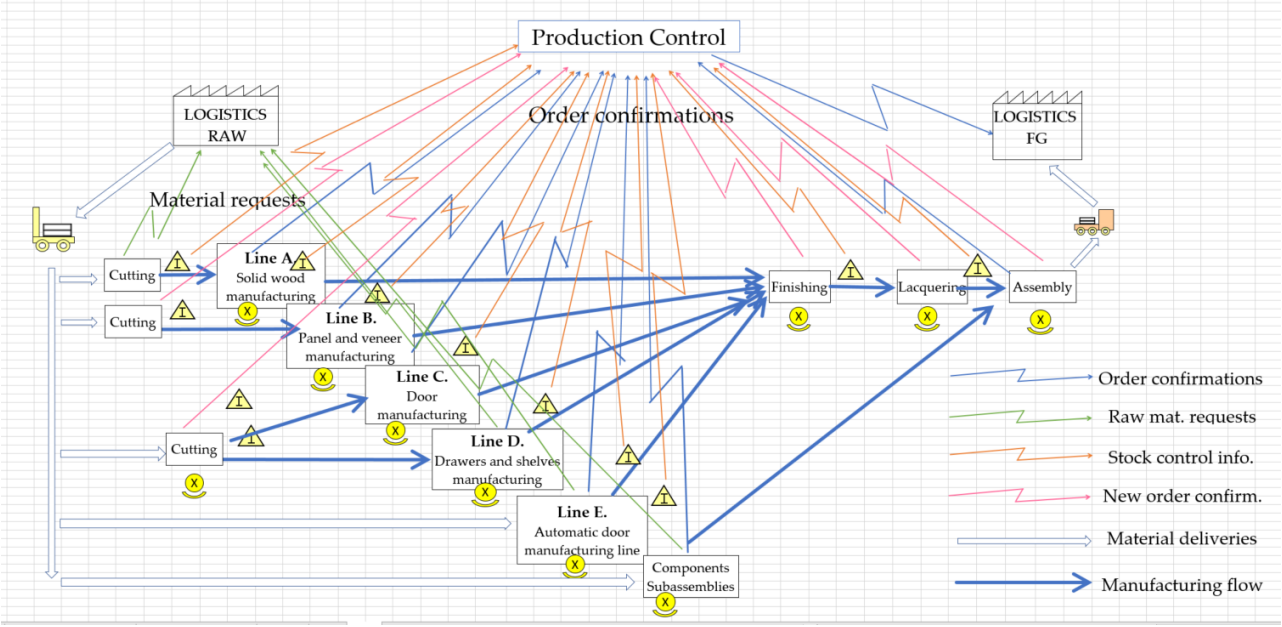

Fig. 2. Process mapping. VSM – Future State

Potential: *Application of Methods-Time Measurement* (*MTM*) for standardizing the times of manual activities performed by operators. Within the framework of Industry 4.0 the Lean tools can be enhanced and integrated with digital technologies to optimize processes and achieve a more detailed analysis of working time.

4. Conclusions

The research direction in engineering and production management regarding the development of Lean techniques and their integration into Industry 4.0 aims primarily at establishing a synergistic connection between the two "paradigms" of production, highlighting their mutual complementarity. The main result has materialized in providing an overview of the opportunity to adapt flexible production in line at Industry 4.0 industrial environment and offering a useful tool in current industrial practice. The research reflects current trends in industry development, with implications for production management and the need to adapt to the dynamic evolution of the industrial and socio-economic environment.

The systematic review of recent specialized literature on techniques applied in modern enterprise management – Lean and Industry 4.0 led to the conclusion that both approaches can be synergistic and contribute to the progress, optimization and efficiency of production processes, adding value and increasing competitiveness. The new strategy integrates flexible manufacturing as a response to rapid changes that are often unpredictable in production. By mapping the value stream, solutions for streamlining the analyzed production system and optimizing material flow have been proposed. Critical points, such as inefficient machines, were identified and replaced, and the production system was resized by creating a new layout using specialized Industry 4.0 software. Significant improvements resulted from reducing cycle times and production costs. The application of Lean techniques in a case study demonstrated the possibility of extending research towards the integration of Lean 4.0. An

important step was taken towards human resource management with the perspective of HMI integration. An integrated real-time monitoring system was practically implemented, along with the digital Andon system, which will be further developed in future papers. The conceptual approach regarding the interdependence of LM and I4.0, along with providing a conceptual integration framework, serves as support for managerial decision-making in organizing companies adapting their production to Industry 4.0 and preparing for the transition to Society 5.0.

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