

Industry 4.0 Enablers and Lean Manufacturing Tools in Respect of Human Resources [†]

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Abstract

The integration of Industry 4.0 (I4.0) and lean manufacturing (LM) has become a crucial approach for industries aiming to enhance accuracy, customization, competitiveness, and environmental sustainability. Manufacturers want to make their factories smarter and their operations more efficient by adopting advanced intelligent solutions. The objectives of this article are to illustrate the impact of I4.0 tools on LM organizations and to clarify the importance of balancing technological progress with human-centered practices. Drawing on academic research, we propose a framework for human resources (HR) integration that fosters adaptability, continuous improvement, and employee engagement in the digital age.

Keywords: Industry 4.0; lean manufacturing; human resources; digitalization; workforce transformation

1. Introduction

Today, manufacturers are facing pressure to optimize their operations and resources while maximizing profitability to remain competitive [1]. With rising raw material costs, supply chain disruptions, and increasing competition, optimizing operations is essential [2].

To do this, industrials are using LM principles that aim to maximize value by reducing waste, standardizing processes, and organizing work [3]. With the development of I4.0, advanced technologies such as the Internet of Things (IoT), cyber-physical systems (CPSs), and big data are being used to improve production and inform decision-making [4]. LM tools and I4.0 technologies are crucial for achieving performance objectives in today's competitive landscape.

LM, with its focus on eliminating non-value-added activities and optimizing processes, has been a cornerstone of efficiency for decades [5]. On the other hand, I4.0 technologies represent the digital transformation of industrial manufacturing through digitalization, seeking solutions that allow information systems to create copies of the physical world.

The integration of I4.0 and LM has become a crucial approach for industries aiming to enhance accuracy, customization, competitiveness, and environmental sustainability [6]. Manufacturers want to make their factories smarter and their operations more efficient by adopting advanced intelligent solutions. The objectives of this article are to illustrate the impact of I4.0 tools on LM organizations and to clarify the importance of balancing technological progress with human-centered practices.



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2. Theoretical Background

2.1. Fundamental Lean Concepts and Tools

2.1.1. Kaizen

The Kaizen approach emphasizes making small, incremental changes over time to improve efficiency, quality, and productivity. Kaizen focuses on involving everyone in an organization, from top management to front-line workers, in the process of identifying opportunities for improvement and implementing solutions [7].

2.1.2. Kanban

Kanban is a visual project management tool used to trigger the replenishment of needed materials based on customer demand. In addition, Kanban aims to streamline processes, reduce waste, and improve productivity by limiting work in progress and promoting continuous flow [7].

2.1.3. TPM

TPM stands for total productive maintenance. It is the autonomous maintenance performed by the operators themselves, which involves proactive maintenance strategies; employee involvement; and continuous improvement efforts to eliminate breakdowns, defects, and accidents.

In addition the goal of TPM is to achieve zero reductions in equipment effectiveness by focusing on autonomous maintenance, planned maintenance, and improvement activities throughout the entire organization [7].

2.1.4. VSM

VSM stands for Value Stream Mapping. It is a visual tool used to map the manufacturing process.

Likewise VSM is a lean management technique that is used to visualize the flow of materials and information required to bring a product or service to a customer. This visualization allows teams to analyze and improve the flow of value, reduce lead times, and enhance overall efficiency and quality [7].

2.1.5. Standardized Work

Standardization is an approach that documents a set of procedures and methods and defines the most efficient way to perform an activity. It involves creating and adhering to standard procedures, protocols, or guidelines that define how tasks and services should be performed and how products should be produced. Standardization helps streamline operations, improves efficiency, facilitates communication, and ensures compliance with industry standards [7].

2.1.6. Poka-Yoke

Poka-yoke is an error-proofing system that allows mistakes to be avoided while performing an activity.

Likewise poka-yoke aims to eliminate defects by incorporating mechanisms that either prevent incorrect actions or provide immediate feedback to the operator if an error is made. By implementing poka-yoke solutions, organizations can improve quality, reduce waste, and enhance overall efficiency and productivity [7].

2.2. Pillars of TPS Structure

The Toyota Production System (TPS) is built on several foundational principles, including the following:

2.2.1. Jidoka (Autonomation)

Jidoka involves building quality into the production process by stopping the line automatically when abnormalities or defects are detected. This allows for immediate attention and correction, preventing defective products from progressing further in the process [7].

2.2.2. Just in Time (JIT)

JIT aims to produce or deliver goods and services exactly when they are needed, in the quantity needed, and at the location needed, thereby minimizing waste and inventory costs.

In addition JIT depends on three elements (continuous flow, tended flow, and Takt time). These pillars form the foundation of TPS and are interrelated, working together to create a lean and efficient production system [7].

2.3. Key Features of Industry 4.0

Industry 4.0 is enabled by technologies and concepts that facilitate the implementation of the Fourth Industrial Revolution, including the IoT, cloud computing, big data, and cyber–physical systems.

These elements drive interconnected, smart manufacturing systems, offering significant benefits but also many challenges for organizations, especially companies that are still working with non-digital systems incompatible with Industry 4.0 technologies.

SMEs may also find the upfront investment in Industry 4.0 technologies substantial.

2.3.1. Cyber–Physical Systems (CPSs)

CPSs are physical and engineered systems whose operations are monitored by a computing and communicating core. CPSs leverage computer-based algorithms to control and monitor mechanisms [7]. Additionally, a CPS integrates cyber and physical components to enable communication, coordination, and control across the system. These systems are prevalent in various domains, including transportation, healthcare, manufacturing, and smart infrastructure, and they are used to improve efficiency, safety, and automation [8].

2.3.2. Internet of Things (IoT)

The IoT refers to a network of interconnected physical devices embedded with sensors, software, and other technologies to collect and exchange data. This enables these devices to communicate and interact with each other, providing a seamless flow of information for improved efficiency and functionality.

Also the IoT is a network of interconnected objects with built-in sensors and computing capability, which enable them to act based on data for intelligent decision-making.

2.3.3. Big Data

Big data refers to a vast amount of data whose size is beyond the ability of a typical database software tool. It refers to extremely large and complex sets of data that traditional data processing methods may find challenging to handle. This data is characterized by its volume, velocity, and variety.

Likewise big data analytics involves extracting meaningful insights from these vast datasets to inform decision-making and uncover patterns, trends, and associations [8].

2.3.4. Cloud Computing and Cloud Manufacturing

Cloud computing and cloud manufacturing are both innovative concepts that leverage the power of the internet and digital technologies to enhance efficiency and flexibility in different domains.

Moreover, cloud computing involves the delivery of computing services over the internet, allowing users to access and utilize resources like servers, storage, databases, networking, and software. It eliminates the need for organizations to own and maintain physical infrastructure. Users can access cloud services from anywhere with an internet connection, enabling collaboration and remote work.

On the other hand, cloud manufacturing extends the principles of cloud computing to the manufacturing industry. Cloud manufacturing integrates cloud computing technologies with advanced manufacturing processes, such as 3D printing and CNC machining. This approach enables manufacturers to access and share manufacturing resources, data, and services through the cloud.

In summary, while cloud computing provides a platform for delivering computing resources and services over the internet, cloud manufacturing applies these principles to specifically enhance manufacturing processes and supply chain management [8].

2.3.5. Robotics

Robots enable autonomous production methods; they are autonomous or semi-autonomous machines capable of carrying out tasks or activities traditionally performed by humans.

At the same time, robotics encompasses various subfields, including mechanical engineering, electrical engineering, computer science, and artificial intelligence [8].

2.3.6. Simulation

Simulation modeling is the method of using models of a system or a process to better understand or predict its behavior.

Furthermore, simulation modeling is a powerful technique used across various disciplines to replicate real-world systems and processes in virtual environments. It involves creating a mathematical model that mimics the behavior of a complex system, then running simulations to analyze and understand how the system behaves under different conditions [8].

2.3.7. Radio Frequency Identification (RFID)

RFID is a technology that identifies and tracks objects in a unique way to provide real-time information. Likewise, RFID technology finds applications in various industries, including retail, logistics, healthcare, manufacturing, supply chain management, asset tracking, access control, and inventory management, among others. It enables organizations to improve operational efficiency, enhance visibility and traceability, reduce errors, prevent theft, and streamline business processes [8].

3. Human Resources Management 4.0

The Fourth Industrial Revolution is transforming industries and redefining the role of HR within companies [8]. It is a paradigm shift in how industries operate driven by advancements in I4.0 enablers. HR professionals should adopt strategies to navigate this transformative era. The challenge in today's rapid technological evolution is how to embrace technological advancements while maintaining a human-centric approach. HR faces both unprecedented challenges and opportunities [9].

3.1. HR Challenges and Opportunities in the Fourth Industrial Revolution

Industry 4.0 enablers have created significant skill gaps across industries, as traditional roles have evolved or become obsolete; the demand for new, advanced skills is growing rapidly [10].

This is clearly seen in the mismatch between the skills employees currently possess and those required to meet the demands of emerging roles and technologies. Many workers lack expertise in I4.0 enablers such as machine learning, the IoT, big data, and cloud computing, which are now critical for industries [11].

The rapid pace of technology development is leaving many workers unprepared for the new tools, processes, and demands in the workplace. Furthermore, this technological advancement is outstripping the ability of traditional educational systems, which often take time to adapt and focus only on theoretical knowledge rather than hands-on skills [12].

The second main challenge in the era of the Fourth Industrial Revolution (4IR) is workforce displacement, as I4.0 technologies are replacing many routine and repetitive tasks, which is leading to unemployment or underemployment, particularly for workers whose skills are no longer in demand.

In addition, data privacy and security have become critical concerns with the adoption of IA tools. As an example, cyberattacks and data leaks expose sensitive personal information, leading to identity theft and financial losses [13]. IA and machine learning are using huge amounts of data, raising concerns about how data is used and protected.

The 4IR offers numerous opportunities for human resources to stay ahead of evolving workforce needs through technology-driven solutions.

IA can be used to build training materials adapted to the needs of each employee that are accessible through mobile devices. Moreover, IA technologies can reduce biases in recruitment, performance reviews, and promotions by analyzing data objectively [13].

3.2. HR Challenges and Opportunities in Lean Organizations

The integration of lean manufacturing tools in industries into HR management presents both challenges and opportunities. Lean organizations have the objectives of maximizing efficiency, minimizing waste, and continuously improving processes to deliver value to customers, which lead to the need to mobilize multiskilled employees who can perform multiple roles and adapt to changing demands. Moreover, lean environments should function with minimal resources, leading to increased workloads and stress [13].

In addition, lean manufacturing tools can present various opportunities for HR management through implementation of the Kaizen mindset; employees are continually encouraged to suggest and implement incremental improvements, leading to an enhanced employee experience and increased efficiency.

Moreover, various lean manufacturing tools like 5S, VSM, and standardized work organize and create a more satisfying work environment, which improves the employee experience.

3.3. Strategies for Integrating HR in Industry 4.0 and Lean Organizations

To overcome the human resources challenges in an increasingly digital organization and benefit from the opportunities created by lean practices aiming to maximize operational efficiency, HR strategies should be aligned with the goals of Industry 4.0 and lean principles.

Being transparent in communicating the goals and benefits behind Industry 4.0 enablers and lean manufacturing tools is the first step to gaining workforce engagement.

HR should ensure that skill gaps are identified in both hard skills (cloud computing, the IoT, etc.) and soft skills (problem solving techniques, RCA, etc.). Then tailored training programs need to be targeted to upskill the workforce. Online courses that offer certification may promote a culture of learning and improve workforce engagement.

Encouraging innovation plays a pivotal role in driving employee creativity and engagement. Human resources can set up a platform to collect suggestions from the workforce and achieve quick wins. This reduces resistance from the workforce and increases their buy-in.

To improve efficiency and workforce engagement, roles and tasks need to be redefined and restructured to achieve a balance between automation and human inputs.

4. Conclusions and Future Directions

The advent of Industry 4.0 enablers and the continued emphasis on lean manufacturing tools have transformed the way industries operate. Human resources are playing a crucial role in ensuring the successful implementation of these paradigms in order to enhance organizational efficiency and employee engagement.

The integration of HR is essential to bridge the gap between workforce skills and technological advancement in the era of the Fourth Industrial Revolution. By upskilling employees, fostering a culture of continuous improvement, and aligning HR practices with organizational goals, HR professionals can drive a successful transition, maximize the potential of their workforce, and achieve sustainable growth in the digital age.

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