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Bringing Lean Manufacturing Principles and Industry 4.0 Technologies Together: A Comprehensive Review

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ABSTRACT

The advent of Industry-4.0 has completely changed the manufacturing environment in recent years, bringing new opportunities and difficulties for companies looking to maximise their efficiency. Simultaneously, lean manufacturing techniques have become well-known for their capacity to reduce waste and streamline operations. The goal of this review paper is to present a thorough examination of how lean manufacturing principles and Industry 4.0 technology are integrated. This article investigates the various A comprehensive literature review of Industry 4.0 technologies and their potential to improve lean manufacturing. This study highlights the benefits, challenges, and future research objectives in leveraging Industry 4.0 to promote lean techniques in the food processing industries by looking at case studies, best practices, and existing research. This study examines how lean manufacturing concepts may be supported by Industry 4.0 technologies like big data analytics, AI and IoT. These technologies can also be utilised to enhance manufacturing operations by increasing value, flow, pull, and perfection. Businesses can achieve operational excellence and build smart factories that are far more lucrative, productive, and efficient by utilising these technologies.

Key Words: Industry 4.0, Lean Manufacturing, KPI, Food Processing, 5S, VSM

INTRODUCTION

Industry 4.0 is a manufacturing industry pattern shift that is changing the way factories run. Modern technologies like the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) have made manufacturing more productive, profitable, and efficient. The adoption of highly advanced technologies like robotics, cloud computing, AI, and IoT in manufacturing is referred to as Industry 4.0. Conversely, a lean system is a production method that emphasizes reducing waste and increasing quality and efficiency.

The objective of this research is to test the potential effects on productivity, lead time, quality, and cost, as well as how lean systems integrate into Industry 4.0 components and can affect these metrics.

Through an examination of Industry 4.0 integration inside a lean system, this study seeks to offer insights into how businesses can make use of these cutting-edge technologies to enhance their operations and maintain their competitiveness.

In the meantime, operational excellence and waste elimination in manufacturing processes have been fuelled by lean manufacturing principles for decades. The goal of this article is to explore how Industry 4.0 technologies can support lean manufacturing concepts and enhance manufacturing operations.

The emergence of business 4.0, defined by the merging of digital technology and the physical world, has brought about a massive upheaval in the industrial business. Industry 4.0 technologies present previously unheard-of chances to boost production, adaptability, and efficiency in manufacturing processes. Simultaneously, the concepts of lean manufacturing are becoming acknowledged as a potent approach to doing away with waste, streamlining processes, and improving overall performance inside organisations. A significant need exists to

investigate how Industry 4.0 and lean manufacturing might be combined to maximise operational excellence, given their potential synergies. To assist practitioners, researchers, and policymakers in utilising Industry 4.0 to promote lean manufacturing, this article will examine the advantages, difficulties, and potential future directions related to this integration. The scope and organisation of this article will be outlined in the following sections, along with a full examination of the main subjects and areas of emphasis.

This paper aims to present the possible advantages that can be obtained by combining Industry 4.0 technologies with lean manufacturing which could include higher output, lower costs, greater quality, increased agility, and superior decision-making skills. The next section moves to Challenges in Implementing Industry 4.0 in Lean Manufacturing which will address the challenges and potential barriers that organisations may encounter when implementing Industry 4.0 technologies in the context of lean manufacturing. It will discuss technological challenges, organisational obstacles, and human factors that need to be considered for successful integration. The real-world case studies and best practices showcasing successful implementations of Industry 4.0 technologies within lean manufacturing environments illustrate practical applications and highlight lessons learned from diverse industries.

Finally, the paper will explore emerging trends and future directions in the integration of Industry 4.0 and lean manufacturing. It will identify gaps in the existing literature and propose potential research avenues that can contribute to advancing knowledge and practice in this field.

By arranging the paper in this manner, we hope to provide a thorough knowledge of the integration of Industry 4.0 technologies with lean manufacturing principles. The analysis of key topics, supported by relevant case studies and research insights, will enable readers to gain valuable insights and practical guidance for leveraging Industry 4.0 to enhance lean manufacturing practices.

LITERATURE REVIEW

The integration of Lean principles with Industry 4.0 technologies has garnered significant attention in recent research, particularly concerning their combined effects on manufacturing and business processes.

Moraes et al. (2023) conducted an extensive review, identifying key technologies within Industry 4.0. Although the study emphasizes technological advancements and efficiency improvements, it also reveals a research gap regarding the contribution of these technologies, when integrated with Lean principles, to achieving broader sustainability objectives. The authors highlight that while much attention is given to technological integration, there is a shortage of research focused on the social, environmental, and business sustainability aspects of combining Lean and Industry 4.0.

In a similar vein, Skalli et al. (2023) examined the synergy between Industry 4.0 technologies and Lean Six Sigma (LSS) practices, which play a critical role in enhancing manufacturing efficiency. Their literature review emphasizes the significant impact of Industry 4.0 on LSS practices and advocates for a more comprehensive approach that aligns with organizational culture, processes, and technologies. The authors call for further research to deepen the understanding of the link between LSS and Industry 4.0, suggesting the creation of integration models, alignment of technologies with existing methodologies, and exploration of opportunities for collaboration. This underscores the need for strategic frameworks that incorporate both technological innovations and the essential organizational and cultural factors for successful integration.

Hines et al. (2023) explored the development of Lean Industry 4.0, observing an increasing shift in research towards socio-technical considerations. Their study identified several significant gaps in the current literature, including the necessity for more comprehensive integration frameworks, a better grasp of the human impact, the need to explore enablers and barriers, and a more thorough assessment of implementation maturity. This highlights that while much is known about the technical integration of Lean and Industry 4.0, there remains a critical need to address the social and human dimensions that influence successful adoption.

Nedjwa et al. (2021) conducted a bibliometric analysis to assess how Industry 4.0 technologies impact Lean management tools. Their research found a positive relationship between these technologies and Lean practices,

indicating that their integration can lead to enhanced productivity, quality, and customer satisfaction. The study identified 38 Lean management tools and 15 Industry 4.0 technologies, analysing how they interact. These findings suggest that a structured approach to integrating Lean and Industry 4.0 can optimize organizational performance.

Overall, the studies emphasize the importance of creating comprehensive frameworks that address the technical aspects of Lean and Industry 4.0 integration along with the socio-technical challenges and opportunities. This approach is essential for unlocking the full potential of Lean Industry 4.0 in modern manufacturing and business contexts.
The integration of Lean management tools with Industry 4.0 technologies, known as Lean 4.0, has been increasingly explored in recent research.

Elafri et al. (2022) pointed out a significant gap in the literature, noting that there are no studies that directly examine the synergies between all Lean methods and Industry 4.0 technologies. Despite this gap, their case study on SAREL Schneider Electric showed considerable advancements in Lean 4.0 application, including a maturity assessment of its implementation. This indicates that while the academic discussion may not fully cover the topic, practical industry examples provide valuable insights into Lean 4.0.

Huang et al. (2022) studied the adoption of Industry 4.0 in manufacturing, with a focus on the transition from lean production to product design. Their research involves modernizing a historical machine used in sheet metal folding by including switch sensors that provide stakeholders with detailed machine condition information. This allowed for a full study of production activities both before and after the use of lean manufacturing practices. The study demonstrates how Industry 4.0 technology can improve lean manufacturing by providing precise data for better decision-making and process optimisation.

Abdulnour et al. (2022) explored the digital transition of SMEs within the framework of personalized mass production. Their research focused on developing strategies for applying Industry 4.0 principles and tools and emphasized the interaction between Lean practices and Industry 4.0. They also highlighted the role of simulation tools in decision-making, showcasing the advantages and problems of utilising these technologies in practice.

Rossi et al. (2022) proposed the D-LEaMIN framework, which outlines a systematic approach to Lean 4.0 implementation through six defined steps. Their study points out the economic implications of digital waste when transitioning to Industry 4.0 without Lean integration. They argue that insufficient incorporation of Lean principles can lead to higher costs for training, maintenance, and equipment, thus highlighting the necessity of a strategic approach to integrating Lean with Industry 4.0.

Rahman et al. (2021) investigated how IoT enhances decision support systems for lean manufacturing. Their findings demonstrated that IoT-enabled data analytics significantly improved process monitoring and decision-making by connecting machines and utilizing Andon systems. This advancement supports better process improvements and operational efficiency through real-time data.

Agosthino Jr et al. (2021) evaluated the impact of Industry 4.0 technologies on Lean professionals, revealing that the integration introduced additional complexity and required closer collaboration between Lean and ICT experts. This collaboration led to better outcomes, illustrating the transformative effect of Industry 4.0 on traditional Lean practices.

Sarotar Zizel et al. (2020) emphasized the critical role of Key Performance Indicators (KPIs) in the successful implementation of Industry 4.0. They stressed that effective KPIs are essential for monitoring efficiency, planning production, identifying bottlenecks, and achieving digitization and automation goals within organizations.

Pagliosa et al. (2019) conducted a systematic review of Industry 4.0 and Lean Manufacturing, identifying nine Industry 4.0 technologies and fourteen Lean practices. Their analysis revealed significant synergies between specific technologies and practices, such as Cyber-Physical Systems and value stream mapping. They proposed

further research to validate these synergies, assess their effects on various operational flows, and evaluate their impact on performance.

Tobias et al. (2017) provided a comprehensive framework to understand the relationships between Industry 4.0 technologies and Lean Production techniques. They categorised these relationships into enablement and empowerment, identifying new connections and the impact of Industry 4.0 on "soft" Lean techniques. Their framework offers valuable insights for future research and practical implementation.

RESEARCH GAP

Optimising performance metrics requires an understanding of the effects of incorporating Industry 4.0 technologies into lean food manufacturing plants. Regretfully, the distinct problems and opportunities posed by these facilities have not received enough attention in the literature. By investigating the connection between Industry 4.0 integration and performance measures in lean food processing environments, this study seeks to close that gap. The information acquired will be very helpful in formulating optimization plans and making decisions. Additionally, this study will pinpoint possible obstacles and constraints when integrating Industry 4.0 elements into a lean framework.

KEY LEAN TOOLS AND THEIR IMPACT

Impact of Lean Tools on Key Performance Indicators (KPIs)

KANBAN
Application: Inventory management and production control.
Impact on KPI: KANBAN helps reduce excess inventory and minimises overproduction by optimising inventory turns. It also improves cycle time by streamlining production flow.

5S
Application: Workplace organisation and cleanliness.
Impact on KPI: The 5S methodology enhances visual management, reduces clutter and waste, improves safety, and boosts employee satisfaction, leading to better overall workplace efficiency.

Value Stream Mapping (VSM)
Application: Analysing and optimising value streams.
Impact on KPI: VSM identifies opportunities for waste reduction, streamlines processes, and improves lead times, contributing to more efficient operations and faster delivery.

Poka-Yoke (Error Proofing)
Application: Reducing defects and errors.
Impact on KPI: Poka-Yoke techniques lower defect rates and rework, resulting in higher quality products and reduced production costs.

Total Productive Maintenance (TPM)
Application: Equipment maintenance and reliability.
Impact on KPI: TPM enhances equipment availability (Overall Equipment Effectiveness, OEE), minimizes downtime, and boosts overall equipment performance.

Single-Minute Exchange of Die (SMED)
Application: Changeover time reduction.
Impact on KPI: SMED significantly decreases changeover time, facilitating quicker production transitions and reducing overall lead times.

Kaizen
Application: Focused process improvement projects.
Impact on KPI: Kaizen targets specific process issues, such as reducing defects, improving cycle time, and increasing productivity, leading to continuous improvements in performance.

Root Cause Analysis (5 Whys)
Application: Problem-solving and defect reduction.
Impact on KPI: The 5 Whys method helps identify and address the root causes of issues, improving quality and

efficiency by eliminating underlying problems.

Just-in-Time (JIT)

Application: Production scheduling and inventory management.

Impact on KPI: JIT reduces overproduction and excess inventory, aligns production with customer demand (Takt time), and optimizes inventory turns.

Cross-Training and Skill Development

Application: Workforce development and flexibility.

Impact on KPI: Cross-training allows employees to perform multiple roles, which decreases downtime and enhances workforce adaptability, contributing to more efficient operations.

Standard Work

Application: Standardizing work processes.

Impact on KPI: Standard Work ensures process consistency, reduces variation, and helps maintain high levels of quality and efficiency.

Visual Management

Application: Communicating information and status visually.

Impact on KPI: Visual Management enhances communication, process control, and adherence to standardised work practices, improving overall operational effectiveness.

Lean Manufacturing Principles

Lean manufacturing focuses on reducing waste and enhancing value in production. Its core principles include:

Value: Deliver value from the customer's perspective.

Flow: Ensure smooth workflow by removing bottlenecks and cutting cycle times.

Pull: Use customer demand to drive production.

Perfection: Continuously refine processes to boost efficiency and eliminate waste.

Industry 4.0 technologies complement these principles by improving operational efficiency. Key technologies include:

Automation: Employs advanced machinery and robotics to streamline repetitive tasks, improving efficiency and reducing errors.

Artificial Intelligence (AI): Analyses large datasets to optimize scheduling, forecasting, and quality control.

Internet of Things (IoT): Sensors and connectivity provide real-time monitoring of equipment and inventory, allowing for preventative maintenance and efficient resource management.

Big Data Analytics: Extracts insights from data to enhance continuous improvement, waste reduction, and quality issue resolution.

Robotics: Collaborative robots assist with repetitive tasks, allowing humans to focus on higher-value activities.

Cloud Computing: Provides scalable, cost-effective solutions for data sharing and remote monitoring, enhancing agility.

Cybersecurity: Protects data and systems from cyber threats, crucial for maintaining operational integrity.

Real-world applications include automation in car manufacturing to improve assembly and AI for energy optimization. IoT sensors can manage inventory in real time, while cloud-based tools facilitate collaboration. Case studies, like those in furniture and food processing, illustrate how integrating these technologies with lean principles leads to operational excellence, higher productivity, and reduced waste.

Benefits and Challenges

Integrating Industry 4.0 technologies with lean manufacturing offers significant **Benefits**

Increased Productivity: Automation and real-time data enhance productivity by optimizing processes and reducing cycle times.

Cost Reduction: Technologies like predictive maintenance cut downtime and extend equipment lifespan, reducing costs. Improved planning and inventory management also lower excess inventory and carrying costs.

Improved Quality: Real-time monitoring and data analysis improve product quality by detecting anomalies and enabling early adjustments.

Enhanced Agility: Digital technologies allow for flexible production systems, enabling quick responses to market

changes and reducing time-to-market.

Challenges

Technological: Implementing Industry 4.0 requires significant investment in infrastructure and integration with legacy systems. Data standardisation and interoperability can also be challenging.

Organisational: Changes in structure, processes, and culture are needed. Resistance to change, digital literacy gaps, and alignment between IT and operational teams can impede progress.

Human Factors: Reskilling and upskilling the workforce is necessary. Addressing fears of job displacement and providing adequate training are crucial for smooth adoption.

Strategies for Success:

Develop a Clear Strategy: Create a roadmap for integration, prioritise technologies, and consider phased implementation to manage risks.

Foster Collaboration: Build cross-functional teams and ensure regular communication to tackle challenges and understand benefits.

Invest in Training: Equip employees with digital skills and involve them in the process to address concerns and enhance acceptance.

Ensure Cybersecurity: Implement robust cybersecurity measures to protect data and systems.

Start with Pilots: Test technologies with small-scale projects to refine approaches before full-scale implementation.

Collaborate with Partners: Work with technology partners and industry networks to gain insights and best practices.

DATA ANALYSIS AND FINDINGS

We observed that several industries have already adopted both Lean Manufacturing (LM) tools and Industry 4.0 (I4.0) technologies, integrating advancements and developing technologies that consider LM and I4.0 factors, parameters, and Key Performance Indicators (KPIs). Despite these efforts, many of these industries struggle to stay competitive and achieve optimal efficiency due to ineffective lean management practices and insufficient knowledge in managing dynamic I4.0 tools and KPIs.

Additionally, numerous industries remain unfamiliar with Lean principles and their implementation. Some have only heard of Lean but lack the practical knowledge or experience needed for effective application.

To address this, we conducted a survey using a sample questionnaire targeting both food and beverage industries that have applied Lean and those that have not. The results revealed that while these industries possess the potential to enhance their efficiency, they fall short due to the absence of proper parameters. During the survey, we also sought permission from industries interested in adopting Lean and I4.0 in their operations.

Following is the list of Companies:

1. Sahyadri Farm
2. Amiable Food Processing Pvt. Ltd.
3. Mahesh Export & Cold Storage
4. Vandana Distilleries Private Limited
5. Exotic Fruits
6. Shiva Sai Exports
7. Nihari Corn LLP Pvt., Ltd.
8. Abhinandan Agrotech
9. RR Foods
10. Vishaka Cold Storage
11. Bhīma Shankar Cold Storage
12. Akshay Agro Industries
13. Shree Chintamani Agro Industries
14. Baswant Honey Bee Industries
15. M. B. Sugar Pvt. Ltd.

Accordingly, below listed problems below were identified in different industry surveys**.** In the industrial sector,

particularly within cold storage and food processing environments, several operational challenges impact efficiency and safety.

Transportation for Cold Storage: Inefficient methods can cause delays, spoilage, and increased costs. Proper logistics are essential for product quality and safety.

Floor Cleaning: Inadequate cleaning can lead to hygiene issues and safety hazards. Effective protocols are crucial for a sanitary environment.

Product Wastage: An average of 3% wastage during processing results in significant losses. Identifying causes is key to improving efficiency.

Inventory Management: Poor practices can cause stockouts and increased costs. Efficient management is necessary for optimal stock levels and waste reduction.

Underutilised Workers: Inefficient use of the workforce leads to lower productivity. Proper management is needed to maximise labour efficiency.

Electricity Shutdowns: Power outages cause disruptions and time losses. Backup solutions are essential to ensure continuous operations.

Waiting Time for Machine Startup: Delays lead to idle times and decreased productivity. Streamlining startup processes is necessary.

Water Wastage: Inefficient crate washing leads to water wastage. Optimising use and improving procedures is needed.

Slippery & Sticky Floors: These pose safety risks such as slips and falls. Proper maintenance and cleaning are necessary.

Rearrangement of Storerooms: Poor organisation results in disorganisation and inefficiencies. Effective layout and management improve accessibility and workflow.

Figure 1: Survey Scenario

PROPOSED METHODOLOGY

Step 1

Plan and organise Walkthrough Audit

Conduct Informal Interview with Plant Manager

Step 2

Introductory Meeting with all process heads and people concerned with process management

Step 3

Gather Primary data, Build a Process Flow Diagram

Step 4

Conduct a survey and monitor

Step 5

Conduct of detailed trials/tests for selected major equipment

Step 6

Analysis of Equipment use (in all forms)

Step 7

Identification and development of problem statement
Step 8
Cost Benefit Analysis
Step 9
Reporting and Presentation to Industry Management.

CONCLUSION

To sum up, lean manufacturing concepts may be supported and production processes can be enhanced by utilizing Industry 4.0 technologies. Businesses may construct smart factories that are much more profitable, productive, and efficient by utilizing advanced digital technologies like IoT, big data analytics, AI, etc... Through the integration of Industry 4.0 technologies and lean manufacturing concepts, businesses may attain operational excellence and promote ongoing enhancements to their manufacturing processes.

A methodical approach that includes goal-setting, evaluation of current operations, creation of an implementation plan, piloting implementation, scaling up implementation, monitoring and evaluating, and continuous improvement is needed to implement Industry 4.0 technologies to support lean manufacturing principles. Businesses can attain operational excellence and successfully incorporate cutting-edge digital technologies into their manufacturing processes by using this methodology.

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