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Innovative Strategies for Lean Manufacturing Laboratory: A Literature Review on Automation and Planning

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A B S T R A C T

The modern industry's drive to increase productivity and reduce waste has spurred research into operational efficiency in laboratories. Although lean manufacturing and automation have proven effective in improving efficiency, their integration into smart laboratories remains limited due to the lack of standardized guidelines. This study evaluates the integration of lean manufacturing and automation in modern laboratories, focusing on smart laboratories. By analyzing 49 relevant scholarly articles from a total of 150 collected via Google Scholar, the research assesses laboratory developments, the application of lean manufacturing, and the integration of automation. The findings reveal global trends in smart laboratories, with a focus on efficiency through lean manufacturing and automation. The study also identifies gaps in the literature, such as the lack of research on fully automated lean laboratories and the need for comprehensive planning across short, medium, and long-term timelines. The study's limitations include the time frame of article publications (2018-2023) and the dominant geographical contributions from Indonesia, India, and Poland. These findings highlight the need for further research to explore innovative strategies for enhancing laboratory efficiency and industrial responsiveness through sustainable technologies.

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1. INTRODUCTION

The global education landscape has undergone significant transformations over the past decades, driven by advancements in information and communication technologies. These changes have influenced teaching and learning methods, facilitated access to educational resources, and promoted cross-border collaboration. Education is no longer confined to physical classrooms but has expanded to digital platforms, enabling students worldwide to learn from anywhere. This trend also presents new challenges, such as the digital divide that needs to be addressed to ensure all students can access quality education. The global education system also emphasizes 21st-century skills, including critical thinking, creativity, and digital literacy, deemed essential to face future challenges (Singh Malik, 2018).

In Indonesia, education has also seen significant changes with the adoption of technology and government policies supporting quality improvement. The Indonesian government has implemented various programs to enhance access and quality, such as the 2013 Curriculum, which emphasizes character development and student competencies. However, challenges remain, including disparities in education quality between urban and rural areas and infrastructure limitations in some regions. The COVID-19 pandemic accelerated the adoption of online learning, although barriers still exist regarding internet access and technological devices in certain areas (Gamage et al., 2020a). Initiatives like "Merdeka Belajar" aim to provide flexibility in the teaching-learning process and encourage school innovation (Damayanti et al., 2023). Higher education plays a crucial role in shaping the future of young generations and serves as a hub for innovation and research. Globally, leading universities compete to attract students and researchers from around the world by offering innovative academic programs and state-of-the-art research facilities (Mense et al., 2018). In Indonesia, higher education institutions also strive to improve education and research quality through international accreditation, collaborations with foreign institutions, and facility enhancements. Challenges faced by Indonesian universities include limited research funding, complex bureaucracy, and the need to continually align curricula with industry needs. Higher education institutions also support the development of human resources ready to compete in the global market through vocational education and skills training programs.

Laboratories in universities are key elements in education and innovation. They provide environments for experiments, research, and the development of new technologies. In the global education landscape, laboratories are equipped with advanced tools and the latest technologies to support interdisciplinary research and international collaboration (Helleno et al., 2023). In Indonesia, laboratories also strive to increase their capacity and quality, despite challenges like limited funding and access to the latest technology. Good laboratories not only support theoretical learning but also provide crucial practical experiences for students, preparing them to face challenges in the workplace. Developing laboratories integrated with industry also focuses on supporting innovation and applying research in real-world scenarios.

Lean Manufacturing Laboratory are specific examples of how laboratories can simultaneously support education and industry (Helleno et al., 2023). Lean Manufacturing, which focuses on efficiency and waste reduction in production processes, is highly relevant in the context of education and industrial training (Guzel & Asiabi, 2022a). These Laboratory provide environments for simulating efficient manufacturing processes, teaching Lean principles (Isack et al.,2023). In Indonesia, developing such Laboratory is crucial for supporting a competitive manufacturing industry in the global market. Lean Manufacturing Laboratory also serve as venues for developing and testing innovations in production processes, which can be adopted by the industry to enhance productivity and efficiency. The interconnection between laboratories, universities, and industries creates an ecosystem that supports the development of new skills and technologies.

Automation has become a cornerstone in the transformation of both global industries and education. In education, automation is applied not only in the learning process but also in administrative operations to enhance efficiency. In industry, automation supports faster, more accurate, and efficient production. Lean Manufacturing Labs are often equipped with automation technology to provide practical experience for students in operating automated systems. In Indonesia, the adoption of automation is crucial for increasing the competitiveness of the manufacturing industry(Brecher et al., 2021). Universities play a role in teaching automation principles and providing practical training through laboratories. Skills in automation are one of the key competencies required in the current job market, along with the development of Industry 4.0 technologies that integrate automation with with equipment such as Programmable Logic Controllers (PLCs), personal computers (PCs), variable frequency drives, three-phase motors, encoders, touch screens, and more (Brecher et al., 2021). All these devices can communicate with each other to form an industrial network. Integrating automation in education and industry creates synergy that strengthens innovation capabilities and adaptability to rapid technological changes. This article makes a significant contribution to the industrial engineering literature by focusing on the development of lean manufacturing laboratories through increased automation levels, especially in Indonesia. The research identifies, evaluates, and synthesizes findings from observed industries, enriching evidence-based practices. This is crucial for industrial engineering students to understand the implementation of lean manufacturing and strategies for enhancing automation in the short, medium, and long term.

2. RESEARCH METHOD

This literature review serves as an essential approach for studying and analyzing fundamental theories, tools, experiences, and lessons learned, making it an invaluable resource for both academic research and practical applications. By systematically gathering and evaluating a wide range of sources, this method not only provides a comprehensive understanding of existing knowledge but also identifies gaps, emerging trends, and areas for future investigation. It allows researchers and practitioners alike to build on established principles, apply proven tools, and incorporate insights from real-world experiences, ultimately enhancing both theoretical understanding and practical implementation in various fields of study or professional practice.

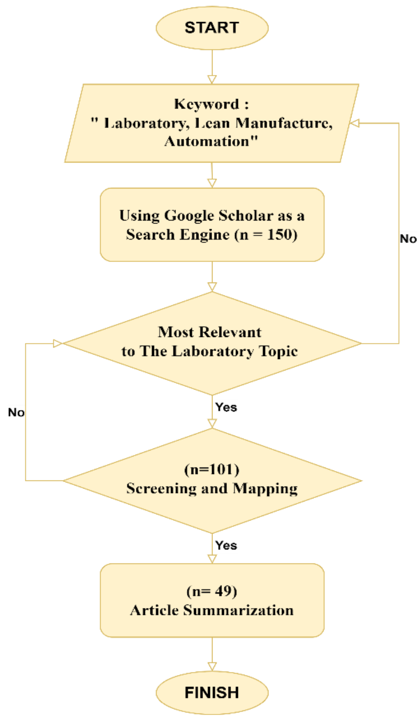

Figure 1. Literature review flowchart

According to Figure 1, this study begins with initial data collection as the first of five steps. The collection is conducted via Google Scholar, covering publications from 2018 to 2024. The keywords used in the article search include "Laboratory," "Lean Manufacturing," and "Automation." The step-by-step activities of the literature review are shown in Figure 1 and described as follows:

- Article Collection
  The process begins by gathering 150 scholarly articles through Google Scholar using the keywords "Laboratory," "Lean Manufacturing," and "Automation." This ensures a wide and diverse literature base.
- Initial Screening
  From the 150 articles collected, an initial screening is conducted to filter out the 101 most relevant articles related to the laboratory topic. This screening considers the research focus, contribution, and source quality.
- Screening and Mapping
  The 101 screened articles are then mapped and further refined, resulting in 49 articles that are truly relevant and aligned with the research focus.
- Article Summarization

The 49 selected articles are summarized based on their identity and research findings, and categorized by research focus, publication year, and nationality of the research. These summaries provide a comprehensive overview and help identify patterns and trends in existing research.

The method employed in this study is exploratory gap research, aimed at identifying and exploring the factors contributing to the lack of research on the development of laboratories for implementing lean manufacturing, as well as strategies for enhancing automation in the short, medium, and long term. The following 49 previous research articles are listed in Table 1.

Table 1. Previous research

No.	Authors	Nationality	Research Outcome
1	(Azamfirei et al., 2023)	Sweden, Norway	Inline quality inspection with automation can help achieve Zero Defect Manufacturing (ZDM).
2	(Mir & Swarnalatha, 2018)	United Arab Emirates	This model uses Arduino as a microcontroller to automate sequential operations in small-scale industrial systems.
3	(Sulistya L.D. et.al.,2019)	Indonesia	Significant improvement in students' understanding of work system design and production system learning, with average scores increasing by 155% after using work station demonstration tools.
4	(Ardi Setiawan & Sulung Rahmawan Wira Ghani, 2023)	Indonesia	5S performance in the laboratory improved from 0.71 (fair rating) to 1.5 (excellent rating) after implementing the 5S method, showing a two-fold increase in laboratory performance.
5	(Mamodiya & Sharma, 2022)	India	Identified four key issues to enhance industrial automation aspects: "Injection Molding Machine Control Methods for New Technology, New Trends in Industrial Automation, Energy Storage in Cogeneration Power Plants & Wireless Data Transmission."
6	(Świder et al., n.d.)	Poland	This laboratory framework has 4 levels of difficulty: basic, advanced, individual/group tasks, and research. Collaboration with industry is crucial for the framework's smooth operation.
7	(Louisa et al., 2023)	Indonesia	This research demonstrates that Conjoint Analysis method can be used to identify important factors considered by consumers in choosing application system-based services. Results can be used to enhance service design to better suit consumer needs.
8	(Bora, 2023)	Indonesia	This research produces a design of a work system and ergonomic laboratory equipped with various measuring instruments and adequate space to support education, research, and community service activities.
9	(Delti, 2018)	Indonesia	This research shows that the optimal speed of a belt conveyor in a time study practical is 1.5 m/s. This speed generates data that meets 95% confidence level and 5% degree of accuracy.
10	(Mukti A., 2023)	Indonesia	The jig production tool reduced 3 work elements and resulted in a 42% time saving, or 57 seconds faster than the grinding cycle time without using the jig.
11	(Lasalewo et al., 2019)	Indonesia	Web-based information system to facilitate laboratory data storage, archiving, and expedite information access.
12	(Isa et al., 2020)	Malaysia	Lean management implementation successfully reduced emergency test response time from 35 minutes to 31 minutes, with an increase in success rate from 82.8% to 93.5%.
13	(Alves et al., 2019)	Portugal	Lean production and ergonomics support each other to improve intelligent, safe, and effective work methods, enhancing company productivity.
14	(Maware et al., 2023)	United States	Online and face-to-face programs show similar performance in two Lean Manufacturing competencies: Lean systems and problem-solving. Online programs exceed face-to-face programs in the third competency, Lean culture.
15	(Helleno et al., n.d.)	Brazil	Integrated laboratory model helps accelerate industrial employee training processes and student learning in production engineering.
16	(Isack et al., 2023)	Namibia, India	Lean principles moderately applied in Namibian medical laboratories. Lean tools like standard operating procedures, root cause analysis, overall equipment effectiveness, and visual management have a positive impact on operational performance, employee motivation, completion time, and cost reduction.
17	(Sukoco et al., 2022)	Indonesia	Line production-based hydraulic pneumatic laboratory layout can enhance automation skills of students. Laboratory layout can be used for Industry 4.0 production process simulation.
18	(Wibowo et al., 2023)	Indonesia	Design and implementation of IoT-based smart laboratory to enhance safety and security in POLNEP's Informatics Engineering laboratory.
19	(Pratama et al., 2022)	Indonesia	Analyzing the effectiveness of virtual laboratories in industrial automation learning in the Industry 4.0 era.
20	(Brecher et al., 2021)	Germany	Describes the importance of automation technology as a key component in production development towards Industry 4.0.

No.	Authors	Nationality	Research Outcome
21	(Elapanda et al., 2019)	India	Integration of Lean Six Sigma framework into laboratory quality management system with specific reference to ISO 17025.
22	(Elisa et al., 2021)	Indonesia	Developing virtual chemistry laboratory learning media to enhance critical thinking skills and scientific processes of students.
23	(Nur Rahmawati et al., 2020)	Indonesia	Building an automatic laboratory asset position tracking system using UHF RFID sensors and K-Nearest Neighbor method.
24	(Suwanto et al., 2022)	Indonesia	Developing computer engineering laboratory seats using ergonomic approach.
25	(Tri Aji Wicaksono et al., 2023)	Indonesia	Decision-making in equipment placement in industrial engineering laboratories based on space limitations using AHP method.
26	(Daywin et al., 2019)	Indonesia	Designing and creating a 3D printer machine to assist in robot component manufacturing process.
27	(Ika Septiana et al., 2019)	Indonesia	Creating a web-based system to monitor student grade developments in industrial engineering laboratories.
28	(Prasetya et al., 2022)	Indonesia	Formulating Business Venturing laboratory development strategies to support learning outcomes and department vision and mission.
29	(Ebojele & Iyawe, 2022)	Nigeria	Measured formaldehyde levels in Anatomy, Histopathology, Medical Biochemistry, and Physiology laboratories used by medical students at an institution in Nigeria. Findings indicated some formaldehyde levels exceeded recommended limits.
30	(Zaman et al., 2023)	China	Identified and evaluated supply chain performance factors by combining a comprehensive literature review and grey decision-making trial and evaluation laboratory (DEMATEL) method.
31	(Abdullah et al., 2020)	Malaysia	Demonstrated that safety leadership significantly influences safety behavior among chemical engineering students in laboratories, with safety knowledge and motivation as mediators.
32	(Ricci et al., 2023)	Italy	Introduced a multidisciplinary lab to design Mixed Reality (MR) interfaces for the Metaverse, with positive student feedback on the adopted teaching methods.
33	(Carayannis & Morawska-Jancelewicz, 2022)	USA/Poland	Discussed Society 5.0 and Industry 5.0 as drivers of future university transformation, emphasizing social innovation and digital transformation.
34	(Ruppert et al., 2023)	Hungary	Developed a demonstration lab for retrofitting Industry 4.0 and Operator 4.0 solutions as education towards Industry 5.0, focusing on smart sensor and sensor technology.
35	(Sukma Donoriyanto et al.,2023)	Indonesia	Develop a web-based E-Learning system for the Industrial Management and Statistic Laboratory to enhance practicum learning.
36	(Kapilan et al., 2021)	India, Finland	Assess the effectiveness of virtual laboratories in enhancing learning during the COVID-19 pandemic.
37	(Irsyad & Hartini, 2024)	Indonesia	Analyze trends in Value Stream Mapping (VSM) research using bibliometric analysis.
38	(Pereyras, 2020)	Philippines	Evaluate the acceptability of a newly developed basic electro-pneumatic control trainer among students and faculty experts.
39	(Grabowska, 2020)	Poland	The study identifies new factory archetypes within Industry 4.0, emphasizing the need for investment in cyber-production solutions and highlighting the changing scope of competition and consumer needs.
40	(Macrorie et al., 2021)	UK	The research explores the integration of robotic and automation technologies in urban settings, proposing a research agenda to understand their implications on urban geographies, infrastructure, and citizen experiences.
41	(Parapouli et al., 2020)	Greece	The review discusses the industrial applications of Saccharomyces cerevisiae, particularly in food, beverage, and biofuel production, and highlights its potential for future biotechnological uses.
42	(Katare Tarun Kumar Yadav, 2019)	India	The study examines the implementation of the 5S lean manufacturing tool in an educational institute, resulting in a significant improvement in workspace organization, reduction in waste, and increased productivity.
43	(Guzel & Asiabi, 2022)	Turkey	The case study demonstrates the successful application of lean manufacturing techniques in an SME furniture factory, leading to reduced production times, decreased quality defects, and a 29% reduction in total workmanship.
44	(Wongkrajang et al., 2020)	Thailand	The implementation of fully automated instrumentation, lean management, and autoverification in urinalysis testing significantly reduced turnaround times and improved productivity in the clinical laboratory.
45	(Mohzana et al., 2023)	Indonesia	The study concluded that the management of science laboratories in high schools is suboptimal due to unimplemented planning, lack of organizational structure updates, limited tools and materials, and insufficient supervision.
46	(Aqidawati et al., 2019)	Indonesia	The research developed a readiness level measurement framework for university laboratories to achieve ISO/IEC 17025 accreditation, highlighting the need for improvements in management and laboratory approaches.
47	(Gamage et al., 2020)	UK, Sri Lanka	The study reviewed approaches to remote teaching and laboratory practices during the COVID-19 pandemic, focusing on maintaining high academic standards and quality student experiences despite limited access to physical laboratories.

No.	Authors	Nationality	Research Outcome
48	(Mišković et al., 2022)	Serbia, Germany	The research developed a cloud-based robotic system for factory automation in a laboratory environment, demonstrating the advantages of real robots for research and potential scalability for real factory applications.
49	(Operti et al., 2021)	Netherlands, Germany, USA	The review highlighted the challenges in scaling up the production of PLGA-based nanomedicines from laboratory to industrial scale, emphasizing the need for proper manufacturing techniques and quality control methods for clinical translation.

3. RESULT AND DISCUSSION

3.1 Distribution Of Research

Based on the articles related to laboratory, lean manufacturing, and automation found in Table 1, this study identifies several key findings. Analysis of the selected 49 articles highlights various approaches and strategies used in the development of laboratories, implementation of lean manufacturing, and automation.

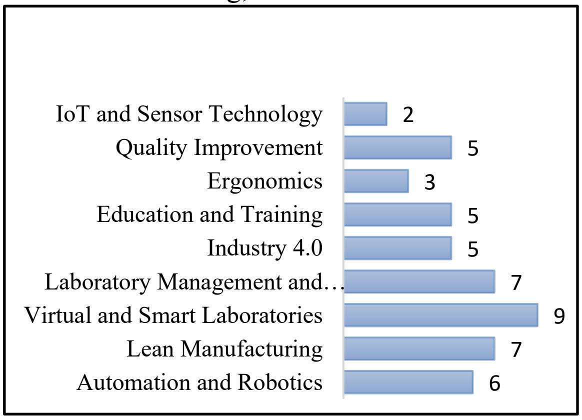

Figure 2. Chart distribution of reasearch object

Based on Figure 2., which illustrates the distribution of 49 articles based on categories of research objects fundamental to development, this study reveals notable patterns in the focus of research related to laboratories, lean manufacturing, and automation. Among the total articles analyzed, the category of Virtual and Smart Laboratories emerges with the highest number of studies, totaling 9 articles, followed by Lean Manufacturing and Laboratory Management and Safety, each with 7 relevant articles. Meanwhile, the categories of Automation and Robotics, Industry 4.0, and Education and Training each feature 6, 5, and 5 articles, respectively. These findings reflect significant interest in the development of smart laboratories and varied emphasis on lean manufacturing and laboratory safety within the selected literature. The discussion on these findings connects the distribution of articles with industry needs and trends. The strong emphasis on smart laboratories and lean manufacturing indicates responses to demands for enhanced efficiency and flexibility in modern industrial environments. Meanwhile, the focus on laboratory management and safety underscores awareness of the importance of safety standards in laboratory operations. Integration of technologies such as automation, robotics, and IoT (Internet of Things) also emerges as key topics, demonstrating a push to implement technological innovations in laboratory management and operations. Overall, this distribution reflects the complexity and multidisciplinary nature of studies related to laboratories, lean manufacturing, and automation, as well as their relevance in industrial development and education contexts.

The analysis of article distribution based on publication years reveals intriguing patterns in research trends related to laboratories, lean manufacturing, and automation. The year 2018 shows an initial count of 3 articles, while 2023 stands out with the highest number of publications, reaching 20 articles, followed by 2019 with 8 articles. The years 2020, 2021, and 2022 exhibit stability in publication numbers. The year 2024 records the lowest number of publications, with only 1 article. This distribution reflects changes in research interests and focuses over time in this field, as visualized in Figure 3.

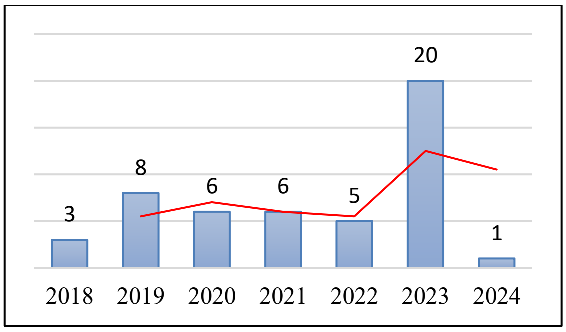

Figure 3. Chart distribution of publication years

The distribution of articles based on publication years provides insights into the dynamics of research in laboratory, lean manufacturing, and automation. The significant spikes in 2019 and 2023 likely indicate primary focuses on laboratory technology development and lean manufacturing implementation during those periods. These trends may reflect responses to technological advancements and industrial demands for faster and more efficient innovations. On the other hand, the decrease in publications in 2024 may suggest more focused research or shifts in research priorities among researchers. Next, the distribution of articles by author nationality shows significant variation in contributions to research related to laboratories, lean manufacturing, and automation from various countries. Indonesia stands out as the largest contributor with 21 articles, indicating substantial activity and contribution from the Indonesian academic community in this field. This dominance underscores Indonesia's focus and increased research capacity.

Following Indonesia, India contributed 3 articles, while Poland and Malaysia contributed 2 articles each. Other countries such as Sweden, Norway, the United Arab Emirates, Portugal, the United States, Brazil, Namibia, Germany, Nigeria, China, Italy, Hungary, the Philippines, the United Kingdom, Greece, Turkey, and Thailand each contributed one article. Additionally, there were collaborations between several countries: Namibia and India; the United States and Poland; India and Finland; the United Kingdom and Sri Lanka; Serbia and Germany; and the Netherlands, Germany, and the United States, each contributing one collaborative article. Visualized in Figure 4. This varied distribution underscores the crucial role of the global academic community in advancing knowledge in laboratories, lean manufacturing, and automation. Indonesia's dominance in publications reflects focused efforts and growing research capabilities domestically, while contributions from other countries highlight the global relevance of this research area.

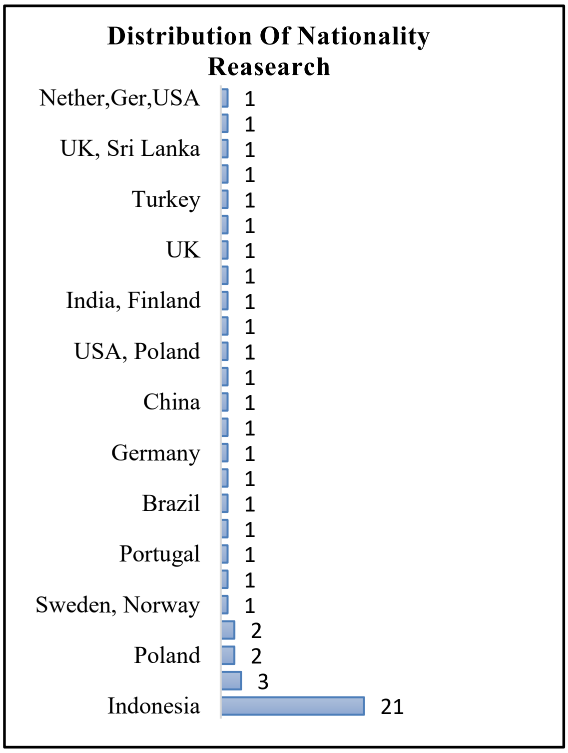

Figure 4. Chart distribution of nationality research

3.2 Comprehensive Insights and Future Research Directions

The distribution of articles based on research focus, publication year, and country of origin provides a comprehensive overview of the dynamics and evolution of research in the fields of laboratory, lean manufacturing, and automation. The correlation between the study focuses depicted in Figure 2 and the publication trends seen in Figures 3 and 4 illustrates how research interests have changed over time, responding distinctly to advancements in laboratory technologies and evolving industrial needs. However, this study also highlights several gaps that warrant attention for future research in the development of laboratories, lean manufacturing, and automation. One such gap is a lack of deep focus on developing lean manufacturing laboratories through higher levels of automation, coupled with comprehensive short-term, medium-term, and long-term planning. These gaps underscore the need for further research to develop innovative strategies that can enhance the efficiency and responsiveness of laboratory systems while optimizing the integration of technology in lean manufacturing environments. By addressing these gaps, future research can make a more significant contribution to the advancement of global industry and education.

4. CONCLUSION

In this study, a comprehensive overview of the dynamics and evolution of research in the fields of laboratory, lean manufacturing, and automation has been presented. The distribution of articles based on research focus, publication year, and country of origin illustrates how research interests have shifted over time in response to advancements in laboratory technology and evolving industrial needs. However, several gaps requiring attention for future research have been identified. One such gap is the lack of deep focus on developing lean manufacturing laboratories through higher levels of automation, along with the need for comprehensive short-term, medium-term, and long-term planning. These gaps indicate the necessity for further research to develop innovative strategies that can enhance the efficiency and responsiveness of laboratory systems, while optimizing the integration of technology in lean manufacturing environments. Overall, this study not only provides a profound insight into current trends in academic literature but also identifies concrete opportunities for advancing knowledge and practices in these fields in the future. By addressing these gaps, it is hoped that future research will make a significant contribution to the advancement of global industry and the enhancement of education quality in laboratory, lean manufacturing, and automation.

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