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A Review on the Implementation and Effectiveness of Lean Manufacturing Strategies for Industrial and Service Sectors

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Abstract

Ensuring a neat, clean, organized, safe, and productive workplace is essential for every organization. Waste and abnormalities may lead to a high loss of productivity and, consequently, capital, along with a significant compromise to the health and safety of the stakeholders. To overcome such challenges, Lean manufacturing is implemented worldwide. The main aim of this technique is to reduce or eliminate certain types of waste (such as those related to motion, transportation, overproduction, waiting time, etc.) that may contribute to financial loss for the companies. The Lean technique is hybridized with other industrial engineering methods such as DMAIC, Six Sigma, Kanban, etc., depending on the situation. This paper reviews some of the vital work in the last five years on implementing Lean manufacturing for various industrial, commercial, and service setups. It first introduces Lean manufacturing, discusses its implementation procedure and tools and techniques, and presents an analysis of previous attempts made by researchers and engineers using Lean to minimize waste, maximize productivity and efficiency, and enhance quality. The article ends with concluding remarks and highlighting the directions for future research. The novelty of this article lies in the fact that along with a basic introduction and review of the last five years' literature, it also sheds light on current trends; recent developments; Lean integration with Six-Sigma, Kanban, Kaizen; automation and digital technology interventions to increase the effectiveness of Lean manufacturing; contribution of Lean in sustainable development.

Keywords: *Artificial Intelligence, DMAIC, Kanban, Lean Manufacturing, Six Sigma, Sustainability, Waste, 5S.*

1. Introduction

Lean manufacturing is a technique that aims to minimize or eliminate waste and promote only value-added activities prompting the improvement of quality of services and/or products and productivity of the systems or processes [1], [2]. In the early 20th century, after World War II, the development of the Toyota production system (TPS) became the foundation of Lean manufacturing. In TPS, just-in-time, Kaizen, and Jidoka were introduced as key Lean concepts. Later in the 1980s, the term *Lean Manufacturing* was coined. From there, the manufacturing companies started adopting Lean practices. In the 1990s, service industries also started incorporating Lean manufacturing interventions. Along with other tools and techniques, the integration of Lean and Six Sigma became popular during that period. In the 21st century, Lean is continuously evolving with the incorporation of automation, digital technologies, and sustainability concepts. Green Lean, digital Lean, and Lean 4.0, etc. are some of the novel Lean strategies being adopted these days.

The manufacturing sector is one of the biggest contributors to the world's gross domestic product (GDP). Doubtlessly, Lean's technique plays a vital role in that. As shown in Figure 1, there are mainly seven types of waste related to defects, inventory, transportation, waiting time,

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motion, overproduction, and overprocessing; which were identified under the Lean concept [3]. Unused talent is considered the eighth waste. Waste reduction facilitates maximum utilization of resources. The concept of Lean manufacturing is governed by five principles, namely, define value, map the value stream, establish a pull system, and pursue perfection. This technique can be hybridized with other industrial engineering methods such as define, measure, analyze, improve, and control (DMAIC), total quality management (TQM), total production system (TPM), and six-sigma, etc. to obtain the maximum benefits of its implementation for products and services [4], [5]. There are many tools such as value stream map (VSM), 5S, fishbone diagram, plan-do-check-action (PDCA), overall equipment effectiveness (OEE), and poka-yoke, etc. available that assist in a successful Lean implementation in organizations. However, the implementation of Lean engineering requires sufficient knowledge and understanding of its principal tools, and techniques [1], [2]. The scope of Lean has become so extensive in the last five years that it has been utilized in cases related to safety, health, and sustainability as well [6], [7].

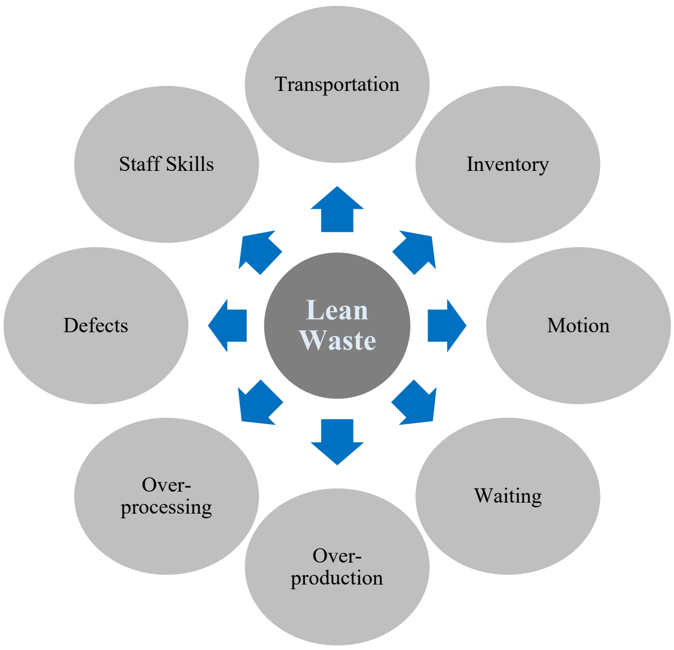

Figure 1. Types of Lean waste.

Here, the other Techniques with which Lean manufacturing can be hybridized or combined to quickly and permanently address the productivity issues in industries/companies are introduced. DMAIC involves five phases i.e. define (defining the problem and causes), measure (measuring the factors responsible), analyze (analyzing the results for problem-solving), improve (improving the processes using devices and implementing solutions), and control (controlling the deviations and procedure to obtain the desired outcomes). DMAIC is considered a problem-solving tool that can easily be synchronized with any project where Lean manufacturing and/or Six Sigma techniques are being implemented. Six Sigma (6σ) is a quality control method useful to make companies profitable by reducing defects and errors and thereby improving business processes. Its blending with Lean manufacturing is known as Lean Six Sigma, which simultaneously utilizes the strengths of both of the individual techniques for early and accurate treatment of waste and improving efficiency and productivity. Kanban is a technique to improve manufacturing efficiency by improving the visualization of parts, products, processes, wastes, inventory, and workflow. It can help to achieve Lean principles in any organization. Kanban is the use of a physical or digital board to display things related to production to update the employees on the progress being made. Kaizen is a continuous improvement tool that entails the involvement of the entire organization. Housekeeping, waste elimination, and standardization are the three pillars of Kaizen. It can effectively identify and treat the waste related to Lean manufacturing for continuous improvement. Sustainability, that is the ability to exist constantly and indefinitely, is becoming popular in Lean manufacturing implementation as well. Green Lean is recognized as a tool for waste reduction and continuous improvement in manufacturing, supply chain, and services. Sustainable practices in Lean and achieving sustainability using Lean, concepts that are important to consider in industrial and service sectors.

One best example of a successful application of Lean with just-in-time, Jidoka, and Kaizen, in any organized company, is in Toyota Motor Corporation and achieving significant benefits, like, reduced inventory costs due to the elimination of large inventories, increased productivity by smoother workflow and lower bottlenecks and downtime, higher product quality through continuous improvement, greater flexibility gained by quick adaptability.

The next section presents some detailed insights into Lean manufacturing that mainly includes challenges and opportunities in its implementation, Lean tools and techniques, performance indicators, and major steps to implement it.

2. Lean Manufacturing Insights

The effectiveness of Lean implementation depends on leadership involvement and optimal utilization of the right tools and techniques. Small incremental changes, fostering Lean culture, and technological interventions for decision-making, are some additional strategies to get the best out of Lean adoption. As discussed before, a successful Lean adoption can result in improved operational efficiency, enhanced product and service quality, and flexibility in production. Cultural resistance, sustaining long-term change, and complexities in the industrial atmosphere (especially in service industries) are some of the challenges to be overcome for the success of Lean adoption.

The barriers to successful Lean implementation are [8], [9], [10]:

- Poor management i.e. ineffective leadership.
- Lack of necessary knowledge and training.
- Lack of resources and/or their improper utilization.
- Lack of communication between internal departments and with customers.

The drivers for successful Lean implementation are [8], [9], [10]:

- Focused, supportive, and visionary management i.e. effective and involved leadership.
- Trained employees with sufficient understanding of Lean fundamentals and utilization of knowledge of Lean tools.
- Continuous improvement philosophy and Lean culture development.
- Waste prioritization.
- Teamwork and effective internal and external communication

Some of the important Lean tools are introduced here below [8], [9], [10].

Value Stream Map (VSM) is a tool to identify and understand the flow of product passes through a sequence of tasks in production from receiving raw material to delivery of final product. The comparison of two VSMs, before and after Lean manufacturing implementation, can help to analyze the effectiveness of the Lean technique. In the service sector, VSM is used to track the flow of information and customer interactions, to further pinpoint the bottlenecks.

5S a Japanese technique is used to organize and systematize the workspaces both industrial and service sectors. The *5S's* are Sort, Set in Order, Shine, Standardize, and Sustain. These are to make the workspaces neat and clean, arrange them, increase their orderliness, and standardize the procedures for sustenance.

The *Fishbone or Cause-and-Effect diagram*, also known as the Ishikawa diagram, is a powerful tool to identify and analyze the root causes of any industrial engineering problem. All possible root causes of all the issues behind any industrial problem are highlighted by a cause-and-effect diagram. For problem-solving and root cause analysis, there is another tool known as *5 Whys*. It is implemented by asking 'why' to reveal the underlying cause of a problem. There are iterations of asking 'why' to reach the root cause.

Plan, do, check, action (PDCA) or *Deeming cycle* is an iterative strategy, a sort of continuous loop, to carry out change and formalize continuous improvement. It consists of stages like planning a change, followed by testing the change, then reviewing the test and analyzing the results, and concludes with taking actions based on the analysis.

Another important tool is *Poka-Yoke* which represents error proofing. While using Poka-Yoke in industrial sectors, the physical designs of processes are changed using physical, functional, and symbolic devices for quality control. Whereas, in the service sector, Poka-Yoke is applied to prevent service failure and for better accuracy. Jigs and fixtures, monitoring instruments, barcodes, and checklists are some examples of Poka-Yoke devices. Quality control and improvement, reduced setup time and scraps, and improved response rate and productivity, are the benefits of using *Poka-Yoke* devices. *Just-in-time (JIT)* is another important Lean tool that helps to ensure that materials, products, and services are available when and where they are needed. JIT minimizes overstocking, inventory costs, and waste.

It requires well-defined metrics and performance indicators that can reflect improvements in efficiency, waste reduction, and operational effectiveness. Lead time, cycle time, inventory turnover, overall equipment effectiveness (OEE), takt time, value-added ratio, etc. are the key metrics. The details of these indicators are as follows:

- *Lead time*: Total process time from its start to completion, including the active work time and all delays. A reduced lead time is expected to recognize processes efficiently and with less idle time.
- *Cycle time*: Time required to complete one cycle of any process or operation. An improved workflow and productivity can be achieved if the cycle time is low.
- *Inventory turnover*: The number of times inventory is used in each period. High inventory turnover to reduce excess inventory and overproduction is desirable.
- *Overall equipment effectiveness (OEE)*: Combining availability, performance, and quality, OEE measures the effective utilization of equipment. A high OEE is an indication of optimal efficiency, minimal downtime and defects, and maximum resource utilization.
- *Takt time*: The rate at which a product is produced to meet customer demand. High takt time indicates alignment of production with customer needs no overproduction and reduced inventory.
- *Value-added ratio*: The time fraction in a process spent on activities that add value. Its high magnitude demonstrates low waste and non-value-added activities.

The typical five core principles, as shown in Figure 2, to be followed to implement Lean are: identify value, map the value stream, create flow, establish a pull system, and seek perfection [1], [8]. The general procedural steps for Lean implementation, as presented in Figure 3, start with recognition of need and end with setting standards for continuous improvement.

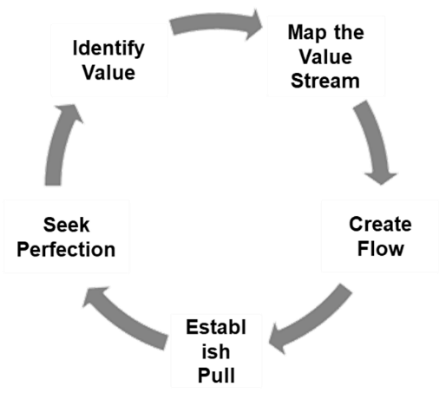

Figure 2. Principles of Lean implementation.

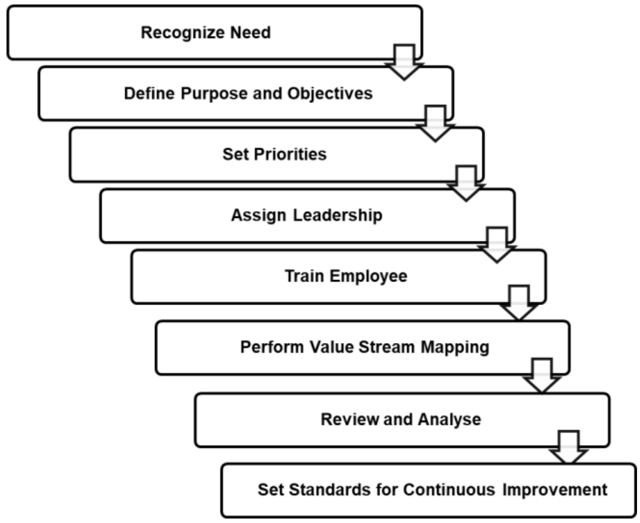

Figure 3. Lean implementation steps.

Next section presents the methodology adopted to carry out this review study and its scope.

3. Review Methodology and Scope

Our review methodology follows a mixed approach, where systematic review, meta-analysis, and scoping review, have been considered [11], [12]. We have done a systematic selection of Lean relevant studies carried out for both industrial and service sectors, followed by a critical synthesis of their findings involving meta-analysis for quantitative measurement of the impact of Lean implementation. Along with that, scoping review approach has also been followed to map the existing review studies on Lean manufacturing and to identify gaps to determine the scope of our review.

Following content analysis, the methodology aims to provide a systematic review of implementation and effectiveness of Lean manufacturing strategies for industrial and service sectors. The detailed methodology steps adopted to carry out this review study are given in Figure 4 and discussed below.

Defining Scope: The scope of this article was defined as where introduction of Lean manufacturing; Lean Manufacturing Implementation Challenges and Opportunities; Lean Tools and Techniques; Matrices and performance indicators for Lean; Lean implementation steps; Analysis of the important recent Previous research on Lean in industrial and service sectors, and current trends in Lean, were finalized as topics to be covered in this review article.

Defining Objectives: The objectives of this review article were defined along with scope, where it was aimed to facilitate academia, research, and industry by providing a detailed understanding of Lean, its application in different sectors, latest developments and current trends, and future work directions, with amassing and analyzing the scattered information reported in the literature.

Literature Search: Keywords with important topics and themes such as Lean manufacturing techniques, 5S, PDCA, just-in-time, value stream map, fishbone diagram, etc.; Lean implementation difficulties; current trends in Lean; Lean wastes; Lean techniques for productivity and quality enhancement, and waste minimization; Lean integration and compatibility with other approaches like Six Sigma etc.; Lean and sustainability; Lean and Industry 4.0, were used to search the literature via Google scholar, ScienceDirect, and Scopus; and the relevant and significant works were identified.

Data Analysis: The information obtained after literature search was systematically synthesized where reported findings, outcomes, claims, and benefits, both qualitative and quantitative type, were analyzed. Moreover, a bibliometric analysis i.e. Quantitative analysis of previous literature to understand the impact of the studies reported on Lean manufacturing and its implementation and interrelation between various Lean related terminologies was done. While doing a literature search and data analysis, articles published with predatory publishers were avoided. Attempts were made to determine how Lean manufacturing techniques are applied differently as well as identically in various industries.

Discussion: A discussion was followed on advantages and difficulties of applying Lean manufacturing techniques in the service and industrial sectors; selection of correct tools and techniques; best practices for implementing Lean manufacturing techniques, and current trends to be followed to stay competitive.

Conclusion: Summarizes the primary findings drawn from the literature search, its review, and data analysis. Further, it provides directions for further research.

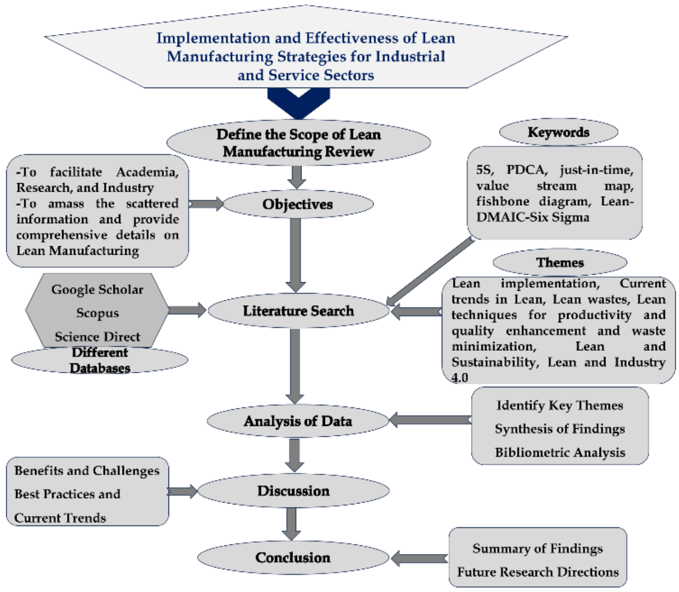

Figure 4. Methodology adopted in the present review study.

There are some existing review studies on Lean manufacturing, its implementation in different sectors, and its integration with other techniques and technologies [13], [14], [15], [16], [17], [18], [19]. They report Lean implementation in small, medium, and large manufacturing industries, with no coverage of the service sector [13], limitedly present Lean manufacturing and Industry 4.0 relationship [14], are based on qualitative analysis and theoretical perspective [15], cover specific topics and contents related to Lean manufacturing such as Lean Six Sigma [16]. Moreover, most of the other existing review studies on Lean manufacturing and its implementation, where the content coverage is wide, are quite old, i.e. conducted long back [17], [18], [19].

Considering that we have developed this review article with a wider scope of covering Lean manufacturing and its implementation in both industrial and service sectors, and current trends including Industry 4.0 and Sustainability interventions. Our emphasis is to present Lean manufacturing integration with other techniques to enhance effectiveness for improved productivity, quality, and efficiency; increased waste minimization; and achieving sustainability. This article facilitates readers in improving competitiveness and cross-industry adaptability of Lean principles. It also guides the use of AI and automation in Lean and about green Lean practices.

Next section presents a detailed analysis of important previous work conducted on implementation of Lean manufacturing in industrial and service sectors.

4. Analysis of Previous Research on Lean Manufacturing Implementation

Lean manufacturing techniques have been used to solve a variety of crucial problems and handle challenges in different industries, service companies, and organizational setups. In this section, we have presented and discussed some of the important examples from the last five years, that mainly show the effectiveness of Lean manufacturing to obtain productivity, profit, safety, and sustainability.

4.1. Industry sector

A group of researchers claimed to achieve a decrease in labor cost of 9.5% and an increase in efficiency of 21%, after implementing Lean in combination with DMAIC while introducing a new process in a rail company for compressor remanufacturing [20]. Lean six-sigma in combination with other tools like TQM and TPM, found effective in reducing waste-like defects in a tire manufacturing firm [21]. An international building system manufacturing company reported a significant increase in productivity after adopting a Lean approach to its manufacturing activities [22]. Intending to improve process capability, Araman and Saleh [23] applied Lean Six Sigma in an extrusion process for aluminum profiles. They achieved an improvement in sigma level from 3.65 to 2.84, 8.5% in process yield, and a huge cost reduction. In another important Lean Six Sigma case study, a tremendous reduction in rejection rates, waste, and lead time, in automobile axle manufacturing industry [24]. This consequently benefited to save costs and space utilization. In a recent investigation, Lean Six Sigma DMAIC approach was employed in the rail car manufacturing industry [25]. The process efficiency of the assembly line was increased by more than 45%, and lead time was reduced by 27.9%. A garment manufacturing company in Africa successfully improved its production after implementing Lean engineering equipped with Kaizen and 5S [26]. With zero bottlenecks and almost negligible non-value-added activities, greatly assisted in achieving production targets. In the wood manufacturing industry, the hybridization of Lean, Six Sigma, Teoria Resheniya Izobretatelskikh Zadatch (TRIZ), and DMAIC was strategized to reduce waste in terms of a 100% decrease in non-value-added activities [27]. For manufacturing companies, defects and waiting time are the two most important wastes. Facing such issues associated with press machines, a manufacturing company applied Lean with PDCA and Poka-Yoke [28]. Waste, as a defect, was treated using PDCA by having the die cleaned and waiting time was reduced using Poka-Yoke where some small devices were introduced to correct the press machine malfunctioning and hence the quick feed of parts with low waiting time overall. [29]. Table 1 presents the summary of some of the more important past attempts at Lean manufacturing implementation in various industrial and service setups.

4.2. Service sector

Not only manufacturing, but even logistics companies also reported great benefits of implementing Lean systems [48]. In this work, with the help of value stream mapping, all non-value-added activities that represented waste were removed. It resulted in improved logistics flow and a significant reduction in the delivery time of the part to the dealer. Six Sigma and TRIZ integrated Lean techniques were employed in the fast-food industry for problem-solving [49]. The flavor-enhancing process was facilitated by a reduction in its completion time from 527 seconds to 48 seconds. Waste of time and energy was reduced. In the service sector, to manage hospital activities, Lean was successfully implemented to identify wastes and reduce non-value-added activities [50].

In an interesting recent study, unnecessary motion-related waste was attempted to be reduced in a workshop of a university using Lean manufacturing [51]. In this work, to create a healthy and safe environment in the workshop space, 5S and systematic layout planning tools were used to achieve efficiency enhancement from 53 to 66% by reducing unnecessary motions and enhancing space utilization. It is known that LSS is an effective root cause identification technology that enables continuous improvement. Having a Six Sigma complemented Lean philosophy, some researchers carried out a case study in the energy service sector [52]. It was reported to achieve overall process improvement with more than seven times improvement in actualization rate and timely meetings of the targets. 5S-equipped Lean manufacturing implementation in a machine shop of an educational institution resulted in more than 5% space utilization enhancement with more than 80% reduction in tool search time [53]. Another interesting study reports the application of a unique Lean-OHS model in the pharmacy laboratory of a university [54]. Before implementation of Lean-OHS model, there were issues such as improper storage of chemicals, unorganized lab space, no arrangements for first aid and protective equipment, etc. A systematic risk analysis was done and 5S with Kaizen interventions were applied. After standardization, they succeeded in achieving better working conditions in the laboratory, a safer environment, and proper storage of chemicals.

Table 1. Summary of important previous research on Lean manufacturing implementation.

Reference	Industry type	Leaning Technique I	Lean Tools	Key Findings
[29]	Plastic industry	Lean and Kaizen	Poka-Yoke,	94.7% increase in productivity
[30]	Aircraft maintenance	Lean	PDCA, VSM,	Significant reduction in Process time
[31]	Garment manufacturing	Digital Lean with Line balancing	IoT, OEE, KPI	Balanced sewing line, Setup time reduction, improved management
[32]	Casting industry	Lean DMAIC	Poka-Yoke	24.63% cost savings, rejection rate reduced by 90%.
[33]	Oil processing	Lean	VSM	Improved waste analysis and reduction in non-value-added activities
[34]	Shipyard	Lean	Waste assessment model	Increased waste identification effectiveness
[35]	Aerospace Production	Lean	VSM - Waste checklist	Identification of motion and waiting wastes, Reduction in lead and cycle times
[36]	Manufacturing Company	Lean		Improvement of production process and elimination of time-consuming tasks
[37]	Shoe making industry	Lean TPM	Gemba walk	50% reduction in accidents
[38]	Apparel Industry	Lean	5S and Poka-Yoke	8% improvement in productivity Reduction in cycle time
[39]	Wood industry	iLeanDMAIC	OEE and VSM	44% reduction in setup time
[40]	Transportation equipment manufacturing company	Lean DMAIC		High-quality welded parts
[41]	Gastronomic equipment manufacturing	Lean	VSM and 5S	6% waste reduction
[42]	Furniture industry	Lean	VSM	27% increase in productivity
[43]	Food industry	Lean	OEE	9% increment in OEE
[44]	Automobile rubber component manufacturing	Lean	VSM	More than a 50% reduction in lead time, setup change over time, and work-in-process inventory.
[45]	Cement industry	Lean	VSM	Better control of excess inventory and elimination of non-value activities
[46]	Transmission tower manufacturing	Lean Kaizen TPM	VSM and 5S	Production lead time was reduced by 62% due to a reduction in setup time change-over time and increased availability.
[47]	Metalworking company	Lean Kaizen	5S, VSM	17.36% increment in availability
[51]	University workshop	Lean	5S, Layout planning	20% efficiency enhancement, reduction in unnecessary motion, enhanced space utilization
[52]	Energy Services Sector	Lean Six Sigma		700% Overall performance improvement
[53]	Education institution	Lean Kaizen	Fishbone diagram, 5S	80% reduction in tool search time, better space utilization, and improved safety.
[54]	Pharmacy Laboratory of University	Lean and OHS	5S, Kaizen	Safety enhancement, Better storage capacity
[55]	Hospital Surgical Process	Lean		Better information and patient flow, Savings in operational budget
[57]	Multi-specialty hospital	Lean	VSM and 5Whys	Identification of medical document papers as the most important waste and converting them into e-documents to save human capital costs

Implementing Lean also resulted in notable performance and service improvement in the health care sector [55], [56], [57]. Emphasizing surgical patients' safety and satisfaction, a project was conducted on implementing Lean for surgical process improvement [55]. Better patient flow, better management of information between healthcare professionals, and improved logistic circuits were the benefits achieved that led to a significant total saving in yearly operational budget. Effective utilization of space in healthcare facilities can be achieved by infusing the layout planning with Lean tools such as 5S, PDCA, mistake-proofing, spaghetti diagrams, etc. [56]. In an interesting case study, Lean was utilized to identify waste in a multispecialty hospital [57]. Effective use of value stream maps and 5Whys resulted in the identification and minimization of the most important waste i.e. medical documents, which were then all converted into e-documents and saved human capital costs.

Next section briefly discusses some current trends in Lean manufacturing.

5. Current Trends in Lean Manufacturing

Some of the emerging trends that present next frontiers in Lean manufacturing include the integration of digital technologies like IoT and AI with Lean, Lean with green practices i.e. sustainability interventions in Lean manufacturing, aligning Lean with automation, and Lean supply chains 4.0, etc. [58], [59], [60]. Enriching Lean with Artificial Intelligence (AI) is beneficial for optimization of the decision-making and quick and accurate responses. AI-supported Lean tools are more refined and can impactfully solve problems and overcome challenges related to waste, cost, and time [59], [60]. Fuzzy and other intelligent techniques are being used to identify dominating waste in Lean manufacturing for different setups [61]. Machine learning models are giving a new edge to learning for improved response and accuracy. These techniques are behind the Lean manufacturing transformation and make it recognized as an important tool in the era of Industry 4.0 and circular economy. As a waste reduction technique, Lean is already a sustainable technique, however, to maximize its impacts to strengthen society, economy, and environment, novel strategies are being developed and incorporated [62]. Sustainability interventions in Lean manufacturing not only make companies profitable but also develop a sense of responsibility towards environment [63]. Digital, green, and Lean manufacturing can overcome many challenges in attaining sustainability. Digital and green or sustainable Lean are identified as the important tools enabling circular economy transition [64]. Under Lean, manual operations are being replaced by robotics process automation benefiting from cycle time and process efficiency [65]. Furthermore, auto-guided vehicles and internet-of-things (IoT) are facilitating to automation of Lean activities [66]. Real-time data for faster diagnostics and management, better process control, customization and personalization, and better supplier integration, are the significant benefits of IoT-enabled Lean manufacturing. To enhance the capability and adaptability of Lean manufacturing, its integration with digital twins is another important leading technology currently [67]. Different Lean Digital twin frameworks are used to automate the process, evaluate times automatically, track production outputs, investigate risks, manage projects, etc. [68]. Adoption of a Lean digital twin framework is not only making companies competitive with improved productivity, efficiency, and flexibility, toward customer requirements; but also enhancing engagement and communication among stakeholders.

Lean integrated supply chain is also under the influence of digital technology intervention [69], [70]. The interaction of Lean supply chain and Industry 4.0 has ensured advanced benefits, such as early identification of wastes, quicker decision-making, and improved planning, and management, in the digital transformation of supply chains [69], [70].

Next section concludes with the analysis of review of past work on implementation and effectiveness of Lean manufacturing and suggests important directions for future research.

6. Conclusion and Future Research Directions

This paper has presented a systematic review of some important past work on implementation and effectiveness of Lean manufacturing. Lean manufacturing is indeed an effective technique for waste reduction at various organization types. It can enhance safety as well as sustainability of industrial systems, facilities, and workplaces. Doubtlessly, Lean has the potential to support the world's GDP by minimizing the cost after treating various types of wastes like non-value-added activities, idle time, productivity loss, etc. Hybridization of Lean with other industrial engineering techniques, multiplying its impacts leads to higher benefits. From garment production to metalworking industry, Lean interventions are indeed effective in productivity, quality, and efficiency enhancement. From education institutes to hospitals, Lean can ensure effective workplace arrangements, better space utilization, and improved safety. Industry 4.0 and sustainability interventions can advance Lean multidimensionally and effectively increase its contribution towards strengthening the societal, economic, and environmental pillars of sustainability. Effective leadership, standardized training, and employee motivation and involvement are the governing factors for the success of Lean implementation. It is recommended that managers and practitioners adopt a proactive approach to infusing Lean with other technologies and harnessing the potential of Industry 4.0, for obtaining competitiveness through improved Lean performance.

The following important future research directions can be proposed from researchers' point of view:

- Future attempts are required to be made towards establishing a strong relationship between digitalization, sustainability, and Lean manufacturing.
- Further work on exploring the effectiveness of the hybridization of Lean manufacturing with other methods like Six Sigma and DMAIC, is required, especially in the service sectors.
- Training and courses are required to be developed to educate teams and stakeholders about digital and green lean.
- Cyber-physical systems and data science approaches are further required to be explored and established towards Lean implementation in different production scenarios.
- Standardized digital twin models for Lean manufacturing are required to be built and a Lean digital twin framework is required to be developed, for different manufacturing processes and systems.
- The societal pillar of sustainability, for safety and well-being, requires more attention while implementing Lean in industry and service sectors.

Authors' Contributions

Kapil Gupta: Conceptualization, Literature Search, Data Collection, Analysis of Data, Synthesis of findings, Review and Discussion, Writing of first draft, Article revision, Final editing

Pallab Sarmah: Conceptualization, Literature Search, Data Collection and Analysis, Synthesis of Findings, Review and Discussion, Article revision

Samuel Loyiso Gqibani: Literature Search and Data Collection, Analysis of Data, Synthesis of findings, Review and Discussion, Article revision and Final editing

Conflict of Interest Statement

The authors declare that we have no known conflicts of financial interests or personal relationships that could have influenced the work reported in this article.

Data Availability Statement

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