Implementation of Lean Manufacturing for Defect Reduction and Sustainable Production in the Metal Casting Industry: A Systematic Literature Review and Bibliometric Analysis

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Abstract. The metal casting industry plays a vital role in the global manufacturing supply chain by supplying critical components for the automotive, construction, and machinery sectors. However, high product defect rates remain a persistent challenge, leading to increased production costs, material waste, and reduced operational efficiency. This study systematically reviews the implementation of Lean Manufacturing in reducing product defects in the metal casting industry while identifying research trends, key success factors, and existing research gaps. A Systematic Literature Review (SLR) based on PRISMA guidelines was conducted and complemented by bibliometric analysis. Data were collected from Scopus, Web of Science, ScienceDirect, and Google Scholar for the period 2010–2025. From an initial pool of 240 publications, 23 articles met the inclusion criteria and were analyzed through qualitative synthesis and bibliometric mapping. Thematic analysis and co-occurrence network visualization using VOSviewer were used to identify dominant research themes and conceptual relationships. The results show a growing research trend since 2015, with major contributions from India, China, and the United Kingdom. Among 12 empirical studies reporting quantitative outcomes, Lean implementation reduced defect rates by 20–60%. Common tools include Value Stream Mapping (VSM), 5S, Kaizen, and Failure Mode and Effects Analysis (FMEA). Overall, the findings confirm that Lean Manufacturing improves production efficiency, product quality, and resource utilization in the metal casting industry, supporting more sustainable manufacturing practices. Future studies should integrate Lean approaches with digital technologies and sustainability-oriented manufacturing strategies.

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1 Introduction

The metal casting industry plays a vital role in the global manufacturing supply chain by producing essential components for the automotive, construction, and machinery sectors [1]. However, the high rate of product defects remains a significant challenge, as it contributes to waste, reduces quality, and lowers production efficiency, ultimately hindering industrial competitiveness [2][3].

From a Lean Manufacturing perspective, defects are one of the key forms of waste that must be eliminated, alongside other types of waste such as overproduction, transportation, overprocessing, motion, waiting, and inventory [4]. Waste elimination aims to improve quality, reduce production costs, and accelerate process flow[5][6].

Lean Manufacturing, which evolved from the Toyota Production System, focuses on enhancing value by minimizing non-value-added activities (Ohno, 2019). Numerous studies have demonstrated the effectiveness of Lean in reducing product defects and improving productivity across various manufacturing sectors [7].

In the metal casting industry, Lean implementation has proven effective in reducing defects and improving process flow across moulding, melting, sand casting, and finishing stages [8]. The application of Lean Six Sigma has also shown substantial improvements through root-cause identification and data-driven problem solving [9][10].

Nevertheless, the implementation of Lean faces several barriers, including human resource readiness, resistance to change, lack of Lean competencies, and limited integration of digital technologies. Recent trends highlight the importance of integrating Lean with sustainability concepts (Green Lean) and Industry 4.0 technologies [11].

However, to date, only a limited number of studies have conducted a systematic review and bibliometric analysis on Lean implementation in the metal casting industry, particularly in relation to defect reduction. Therefore, this study aims to:

a. Analyze the implementation of Lean Manufacturing for reducing product defects in the metal casting industry.
b. Identify success factors and barriers.
c. Map research trends in Lean Foundry through bibliometric analysis.
d. Highlight research gaps and propose recommendations.

Academically, this study contributes to strengthening the literature on Lean Manufacturing in the metal casting industry, particularly regarding process efficiency, quality, and sustainability [12]. Practically, the findings are expected to provide guidance for industry practitioners in implementing Lean strategies that are integrated with digital technologies and environmental sustainability principles to enhance competitiveness and long-term performance [13].

2 Method

This study uses a Systematic Literature Review (SLR) method based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, complemented by a bibliometric analysis using VOSviewer [14]. This approach is used to identify, evaluate, and synthesize previous research on the application of Lean

Manufacturing for reducing product defects in the metal casting industry, while also mapping research trends and scientific collaboration in this field.

2.1 Research Questions

This study aims to address four main research questions:

a. What are the publication trends regarding Lean in the metal casting industry?
b. Which Lean tools are most frequently used and proven effective?
c. What factors influence the success of Lean implementation?
d. What research gaps still exist?

2.2 Databases

The literature search was conducted using Scopus, Web of Science, ScienceDirect, and Google Scholar with the following keywords:
("Lean Manufacturing" OR "Lean Production") AND ("Defect Reduction" OR "Product Defect") AND ("Metal Casting Industry" OR "Foundry").

2.3 Article Selection

Inclusion criteria included: articles published between 2010–2025, full-text availability, and relevance to Lean and the metal casting industry. A total of 23 articles were selected for analysis, as shown in **Fig. 1**.

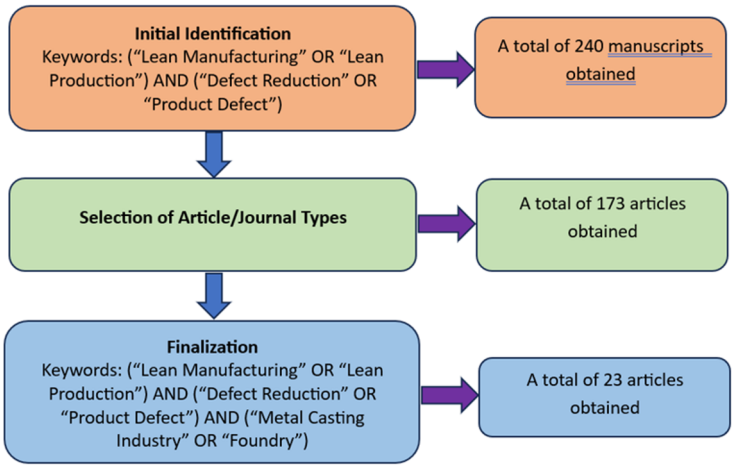

Fig. 1. PRISMA Flow Diagram for Article Selection

2.4 Analysis

Qualitative analysis was conducted to identify the methods, Lean tools it used, implementation outcomes, and the factors influencing the success of Lean application in reducing product defects. Bibliometric analysis was performed using VOSviewer software to map publication trends, dominant keywords, author collaboration networks, and citation networks.

3 Results and discussion

3.1 Results

3.1.1 Publication Trends

Based on the PRISMA-guided search and selection process, 23 relevant articles were identified from an initial pool of 240 publications and subsequently analyzed through qualitative and bibliometric approaches. Overall, research trends on Lean Manufacturing in the metal casting industry show a significant increase between 2018 and 2021, with a peak in publications occurring in 2020, as illustrated in **Fig. 2**. Most studies originate from India, China, and several European countries, among others, indicating strong interest in improving quality through production efficiency, as shown in **Fig. 3**.

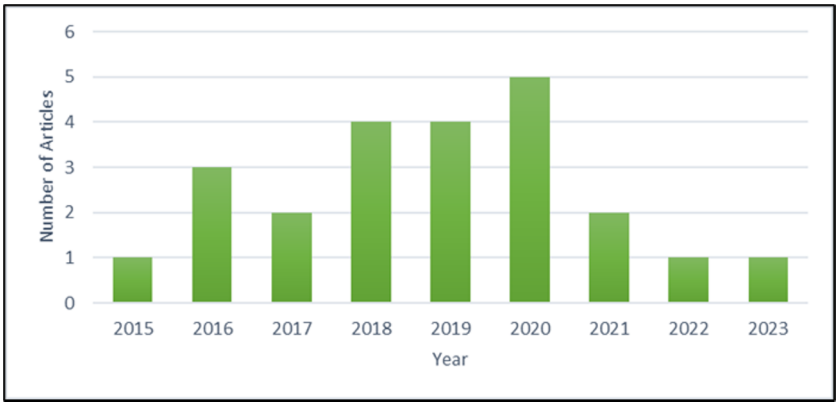

Fig. 2. Year of Publication

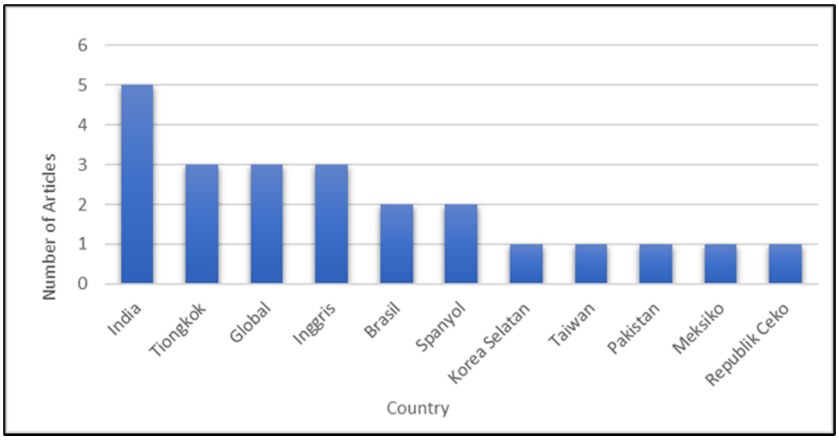

Fig. 3. Countries of Origin the Researchers

3.1.2 Bibliometric Results

The bibliometric analysis conducted using VOSviewer shows several dominant keywords, including "Lean Manufacturing," "Defect Reduction," "Product Quality," "Metal Casting Industry," and "Foundry". In addition, emerging trends such as Digital Lean, Industry 4.0- and Zero-Defect Manufacturing indicate a research direction that increasingly integrates Lean with digital technologies, as illustrated in **Fig. 4**.

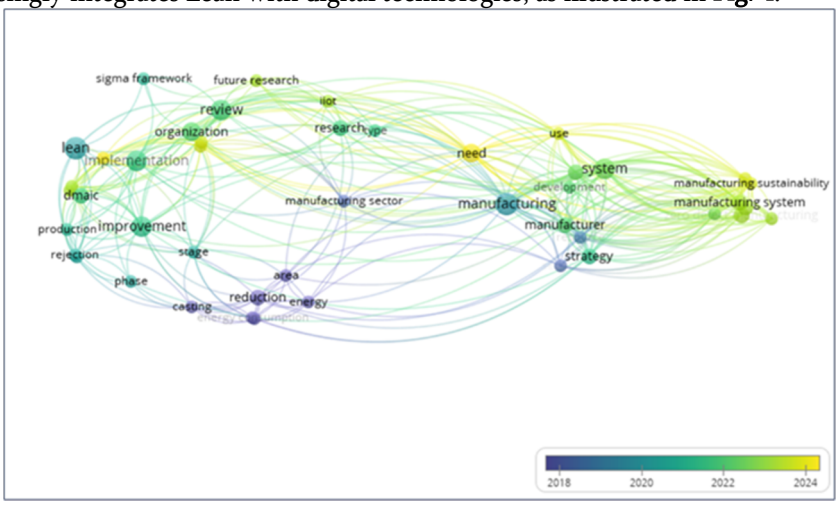

Fig. 4. Visualization map of the co-occurrence network of titles and abstract keywords, and visualization map of keyword frequency evolution over time

3.1.3 Most Commonly Used Lean Tools

Qualitative analysis shows that the most frequently used and effective Lean tools include Value Stream Mapping (VSM), 5S, Kaizen, DMAIC and FMEA & SPC as illustrated in **Fig. 5**. Most studies report reductions in product defects ranging from 20% to 60%.

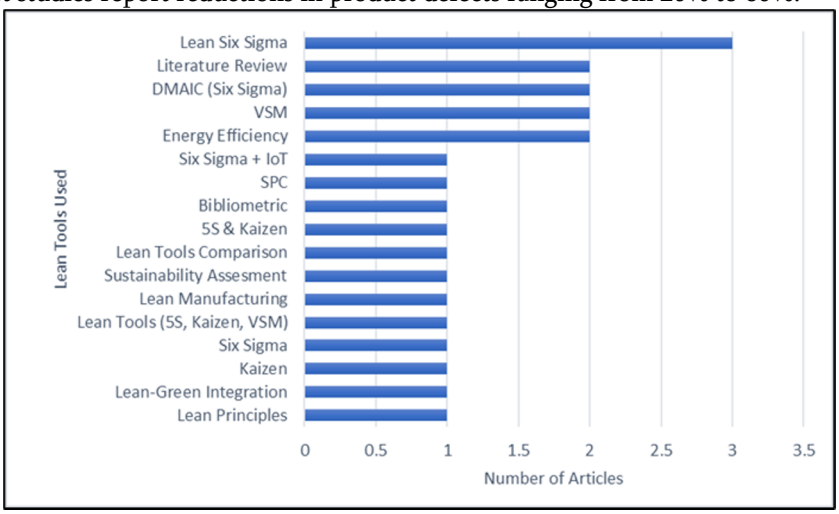

Fig. 5. Lean Tools Used

3.1.4 Summary of Research Findings

A summary of research findings from several studies on the implementation of Lean Manufacturing in the metal casting industry is presented in **Table 1**.

Table 1. Summary of Lean Manufacturing Implementation Studies in the Foundry Industry

No.	Authors	Country & Research Object	Method	Research Findings
1	Pathania et al. (2021)	India – Small and medium metal casting industries	Quantitative case study	Lean Six Sigma reduced product defects, shortened process time, and improved operational efficiency.
2	Salonitis et al. (2016)	China – Metal casting with focus on energy efficiency	Experimental & technical analysis	Energy-efficiency measures improved process sustainability and reduced power consumption without affecting quality.
3	Raju (2016)	Global – Lean Six Sigma in various manufacturing sectors	Systematic Literature Review (SLR)	Developed a conceptual framework for Lean–Six Sigma integration and systematic implementation guidelines.
4	Vinodh (2019)	Global – Lean & Green Manufacturing	Narrative literature review	Identified links between Lean and sustainability and proposed an integrative efficiency–environment model.
5	Oprime et al. (2023)	Brazil – Automotive component supplier	DMAIC-based case study	DMAIC reduced defects and improved production process stability.
6	Jara et al. (2023)	Peru – A small metalworking company	Case study; VSM; 5S; Systematic Layout Planning (SLP); JIT	Lean tools increased productivity and significantly reduced cycle time.
7	Pereira et al. (2019)	Portugal– Mould industry – mould design and manufacturing process	Lean Six Sigma; DMAIC; VSM; Pareto; OEE	Improved machine effectiveness (OEE) and reduction of major downtime causes.
8	Huang et al. (2022)	Taiwan-SME in the metal products industry	Case study; VSM; PDCA; 5S; SMED	Lean improved process efficiency and reduced lead time.
9	Patel (2023)	India – Sustainability-	Conceptual study & case study	Lean–Green integration improved energy

No.	Authors	Country & Research Object	Method	Research Findings
		oriented metal casting.		efficiency and reduced waste.
10	da Silva et al. (2023)	Brazil-Casting process using scrap-based niobium.	LCA (OpenLCA, Ecoinvent, CML).	Scrap niobium lowers environmental impact; sand recycling causes most impact.
11	Ucurum et al. (2016)	Turkey – Production of cast iron (GGG40) components.	SPC (X-R chart), capability analysis (Cp, Cpk)	Process was stable and capable; all parameters within control limits; SPC effectively improved quality control.
12	Ramesh, G., & Reddy, N. S. (2019)	India-Industri foundry (pabrik pengecoran).	Application of Lean Manufacturing tools such as Value Stream Mapping (VSM), 5S, and Kaizen.	Reduction of defects and improvement of productivity in the casting process.
13	Kumar et al. (2021)	India – Aluminum casting industry	Quantitative & environmental analysis	Energy efficiency and environmental metrics are essential for sustainable production.
14	Khot et al. (2019)	India – Small-scale foundry industry	Lean Manufacturing using Kaizen	Improved productivity and reduced waste without major financial investment.
15	Barot et al. (2020)	India-Cast iron foundry	Lean Six Sigma (DMAIC)	LSS feasible and effective; defects reduced and process stability improved.
16	Saetta & Caldarelli (2020)	Italia – Industri foundry (Green Foundry	Case study on Lean Production	Lean improves efficiency and reduces environmental impact.
17	Yadav et al. (2021)	India – Sand casting of Aluminium LM04	Life Cycle Assessment (LCA) using CML	Melting process gives highest environmental impact; major contributions from energy use.
18	Vanli et al. (2018)	Turkey – Die casting foundry	Industry 4.0 framework & digitalization analysis	Industry 4.0 improves monitoring and efficiency.
19	Kumar et al. (2021)	India – Steel casting plant	DMAIC experimental study	DMAIC improved quality stability and reduced variation in casting results.

No.	Authors	Country & Research Object	Method	Research Findings
20	Alvarez (2018)	Spain – Automotive metal industry	Action research	5S and Kaizen reduced scrap rates and improved workplace discipline.
21	Joshi & Jugulkar (2014)	India – Metal casting defects	QC tools (Pareto, Fishbone, Check Sheet)	Main defects identified; causes traced to sand quality and process issues; improvements reduced defects.
22	Patwari et al. (2024)	Bangladesh – Metal casting process	Manual analysis + digital optimization	Defect identification and combined optimization successfully reduced defects.
23	Kannan et al. (2020)	India – Traditional metal casting	Quantitative case study	Lean principles reduced cycle time, improved machine utilization, and increased casting efficiency.

3.2 Discussion

This study interprets the findings of the systematic literature review and bibliometric analysis on Lean Manufacturing in the metal casting industry by addressing the research questions (RQ).

Regarding RQ1, the results indicate a growing research interest since 2015, reflecting the increasing need for efficiency and quality improvement in casting operations. Most publications originate from countries with strong manufacturing sectors, such as India, China, and the United Kingdom, suggesting that Lean approaches are widely explored to address operational inefficiencies and defect-related challenges.

In relation to RQ2, the literature shows that several Lean tools are commonly applied to reduce product defects, particularly Value Stream Mapping (VSM), 5S, Kaizen, and Failure Mode and Effects Analysis (FMEA). Empirical studies report that Lean implementation can reduce defect rates by approximately 20–60%, demonstrating its effectiveness in improving process control and product quality in foundry operations.

Concerning RQ3, the success of Lean implementation depends largely on organizational factors, especially management commitment, employee involvement and training, and a culture of continuous improvement. These elements support sustainable process improvement and effective problem-solving at the operational level.

3.2.1 Success Factors and Barriers to Implementation

Key success factors include management commitment, employee involvement and training, and a culture of continuous improvement. However, several barriers remain, such as resistance to change, inconsistent application of Lean tools, lack of real-time production data, and limited understanding of Lean principles.

3.2.2 Research Gaps

Regarding RQ4, several gaps remain in the literature. These include the limited number of longitudinal studies on Lean implementation in foundries, the early-stage integration of Lean with Internet of Things (IoT) technologies, the scarcity of research on Lean Green Foundry practices, and the lack of studies addressing environmental and ergonomic aspects in casting operations.

4 Conclusion

This study synthesizes the implementation of Lean Manufacturing in the metal casting industry through a systematic literature review and bibliometric analysis. Addressing RQ1, the results indicate a growing research trend in Lean Manufacturing applied to casting operations, reflecting increasing efforts to improve production efficiency and product quality.

Regarding RQ2, several Lean tools are commonly applied to reduce product defects, including Value Stream Mapping (VSM), 5S, Kaizen, DMAIC, and Statistical Process Control (SPC). Empirical studies report defect reductions ranging from 20% to 60%, demonstrating the effectiveness of Lean practices in improving process control and operational performance.

In relation to RQ3, successful Lean implementation is strongly influenced by management commitment, workforce training, and the development of a continuous improvement culture. However, challenges such as resistance to change and limited understanding of Lean principles remain significant barriers.

Finally, addressing RQ4, this study highlights several research gaps, including the need for longitudinal studies, the integration of Lean with digital technologies such as IoT, and the development of Lean Green Manufacturing approaches. Overall, Lean Manufacturing remains a relevant strategy for enhancing efficiency, quality, and competitiveness in the metal casting industry.

Future research should focus on integrating Lean Manufacturing with IoT and digital manufacturing technologies to enhance process monitoring and efficiency. In addition, longitudinal studies are needed to evaluate the long-term impact of Lean implementation. Researchers should also explore Lean Green Manufacturing approaches to support environmentally sustainable practices in the metal casting industry.

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