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ANÁLISE BIBLIOMÉTRICA DOS ESTUDOS SOBRE A AVALIAÇÃO DA MATURIDADE DO LEAN NAS PMES
BIBLIOMETRIC ANALYSIS OF STUDIES ON LEAN MATURITY ASSESSMENT IN SMES
ANÁLISIS BIBLIOMÉTRICO DE ESTUDIOS SOBRE LA EVALUACIÓN DE LA MADUREZ DE LEAN EN PYMES

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RESUMO

Introdução: Os princípios Lean têm contribuído significativamente para a eficiência e competitividade das pequenas e médias empresas (PMEs). Contudo, persistem lacunas na literatura científica, particularmente na avaliação da implementação do Lean, nos seus impactos no desempenho e na análise das competências de gestão e conhecimento relacionados.
Objetivo: Identificar e analisar as tendências de investigação sobre os princípios Lean e a maturidade Lean em PMEs, avaliando as principais contribuições científicas, os artigos mais citados, os autores mais influentes e as lacunas de investigação que possam orientar trabalhos futuros.
Métodos: Foi realizada uma análise bibliométrica de artigos publicados entre 2010 e 2024, disponíveis nas bases Web of Science e Scopus. A análise foi suportada pelos softwares Bibliometrix, em R Studio, e VOSviewer, permitindo a visualização de redes de citações, coautorias e palavras-chave.
Resultados: São evidenciadas tendências emergentes e lacunas significativas na investigação sobre maturidade Lean em PMEs. Foram identificados artigos, autores e tópicos de maior destaque, bem como a necessidade de mais estudos sobre a avaliação da maturidade Lean e os seus impactos nas práticas organizacionais e no desempenho das PMEs.
Conclusão: Este estudo fornece uma visão abrangente do estado da arte sobre os princípios Lean e a maturidade Lean em PMEs. Ao identificar lacunas e propor direções futuras de investigação, contribui para o avanço das práticas Lean, promovendo uma gestão mais eficiente e competitiva.

Palavras-chave: análise bibliométrica; Lean; modelos de maturidade; VOSviewer; R-Studio´s Bibliometrix

ABSTRACT

Introduction: Lean principles have significantly contributed to the efficiency and competitiveness of small and medium-sized enterprises (SMEs). However, gaps remain in the scientific literature, particularly in assessing Lean implementation, its impact on performance, and analyzing management competencies and related knowledge.
Objective: Identify and analyze research trends on Lean principles and Lean maturity in SMEs, evaluating key scientific contributions, the most cited articles, the most influential authors, and research gaps that may guide future studies.
Methods: A bibliometric analysis was performed on articles published between 2010 and 2024, available in the Web of Science and Scopus databases. This analysis used the software Bibliometrix, in R Studio, and VOSviewer, allowing the visualization of the number and networks of citations, co-authorships, and keywords.
Results: The main trends and gaps in Lean maturity in SMEs are highlighted in this study. The most prominent articles, authors, and themes were identified, as well as the need for more in-depth studies on the assessment of Lean maturity and its impacts on organizational practices and the performance of SMEs.
Conclusion: This study provides a comprehensive overview of the literature on lean maturity and its principles in SMEs by identifying gaps and proposing future research directions, contributing to advancing lean practices, and promoting more efficient and competitive management.

Keywords: bibliometric analysis; Lean; maturity models; VOSviewer; R-Studio´s Bibliometrix

RESUMEN

Introducción: Los principios Lean han contribuido significativamente a la eficiencia y competitividad de las pequeñas y medianas empresas (PYMEs). Sin embargo, persisten lagunas en la literatura científica, particularmente en la evaluación de la implementación de Lean, su impacto en el rendimiento y el análisis de las competencias de gestión y el conocimiento relacionado.
Objetivo: Identificar y analizar las tendencias de la investigación sobre los principios Lean y la madurez Lean en las PYME, evaluando las principales contribuciones científicas, los artículos más citados, los autores más influyentes y las lagunas de investigación que podrían orientar los trabajos futuros.
Métodos: Se realizó un análisis bibliométrico de artículos publicados entre 2010 y 2024, disponibles en las bases de datos Web of Science y Scopus. El análisis fue respaldado por el software Bibliometrix en R Studio y VOSviewer, permitiendo la visualización de redes de citas, coautorías y palabras clave.
Resultados: Se identificaron tendencias emergentes y lagunas significativas en la investigación sobre la madurez Lean en PYMEs. Se destacaron los artículos, autores y temas más relevantes, así como la necesidad de realizar más estudios sobre la evaluación de la madurez Lean y su impacto en las prácticas organizacionales y en el rendimiento de las PYMEs.
Conclusión: Este estudio proporciona una visión integral del estado del arte sobre los principios Lean y la madurez Lean en PYMEs. Al identificar lagunas y proponer direcciones para futuras investigaciones, contribuye al avance de las prácticas Lean, fomentando una gestión más eficiente y competitiva.

Palabras clave: análisis bibliométrico; Lean; modelos de madurez; VOSviewer; Bibliometrix de R-Studio

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INTRODUCTION

Currently, companies share a common concern in definng a strategy for continuous improvement, with the crucial application of this philosophy throughout the organizational culture.

Over the last few years, small and medium-sized enterprises (SMEs) worldwide have increasingly embraced Lean Manufacturing practices. This trend is primarily attributed to the proven advantages of Lean, including cost savings (Anand & Kodali, 2009), enhanced performance and business growth (Driouach et al., 2019), increased productivity (Kumar et al., 2022), improved competitiveness in global markets (Anand & Kodali, 2009), and significant advancements in quality, flexibility, and efficiency (Liker & Yu, 2000; Dennis, 2007; Bhamu & Sangwan, 2014). The implementation of Lean has become a challenge, particularly for SMEs, where many struggle to engage in Lean programs and carry out the Lean transformation (Belhadi & Touriki, 2016; Alkhoraif et al., 2019). Companies have problems eliminating waste and being able to compete with their competitors; the Lean Manufacturing philosophy has been widely adopted, although more visibly in large companies than in SMEs (Zanin et al., 2023). Although SMEs encounter barriers in implementation, they are still in the initial stage, with a lack of knowledge in using tools to assess their Lean maturity (Comelli et al., 2019).

SMEs often remain in the early stages of Lean implementation due to limited knowledge of Lean principles, insufficient training, resource constraints, internal resistance, and the absence of appropriate maturity assessment tools. SME lean implementation challenges include critical success factors, suitability of lean tools, and measuring lean change in SMEs (Belhadi et al., 2018). Overcoming these barriers requires targeted training, customized assessment frameworks, and external support to build Lean capabilities and facilitate progression beyond the initial phases (Qureshi et al., 2022).

Furthermore, many SMEs' lack of strategic planning and organizational structure creates additional challenges in adopting Lean Manufacturing practices (Moeuf et al., 2016). Assessing Lean maturity is therefore essential, as it helps identify areas for improvement and supports achieving performance and growth objectives.

Although Lean principles and tools are widely recognized as critical enablers of competitive advantage, certain areas remain underexplored in the literature. These include the development of comprehensive metrics for assessing global Lean implementation and creating suitable evaluation frameworks to measure effectiveness and Lean maturity levels (Pakdil & Leonard, 2014).

Assessing the maturity level of Lean implementation is necessary for continuous improvement, as it helps identify weaknesses and areas that require further development (Barros et al., 2020). It is important to examine various studies addressing Lean maturity assessment models to provide a clearer, simpler, more direct, and more comprehensive view of results, covering all areas of Lean.

This study follows the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) guidelines to ensure methodological transparency and alignment with international standards. These guidelines provide a structured and rigorous framework for conducting and reporting scoping reviews, enhancing the study's credibility and replicability.

1. LITERATURE REVIEW

The concept "Lean" was first introduced by Krafcik (2003) during his academic research in the early 1990s. Later, Womack & Jones (2003) published the book "The Lean Mindset in Companies: Eliminate Waste and Create Wealth", leading to the popularity defined by Toyota's production system (Holweg, 2007). Taiichi Ohno was one of Japan's creators of the Toyota Production System (TPS) after World War II in the 1950s. It emerged as a national survival strategy to compete in the post-war market after the decline of Fordism. This philosophy originated from the need to increase productivity and reduce factory costs, giving rise to the new production paradigm known as Lean Production or Lean Manufacturing (Womack et al., 1990). Lean production guides companies toward optimizing their production by adhering to principles such as waste elimination and providing value to the customer (Turgay et al., 2023).

Danese et al. (2018) highlighted a growing adoption of Lean tools and concepts across various domains, including production and operations management, technology management, and production planning and control, particularly emphasizing Lean studies within supply chain management. Sachdeva (2017), Lean principles can provide benefits to any industry; however, improper implementation may result in wasted organizational resources and diminished employee trust in Lean practices (Alipour et al., 2022).

In recent years, applying Lean principles has gained increased attention across various industries (Danese et al., 2018; Alabi, 2024). Womack & Jones (2003) outlined a timeline for Lean implementation, which consists of four key phases: initiation, organizational development, installation of business systems, and achieving complete transformation. Similarly, Anvari et al. (2011) proposed a roadmap that identifies specific tools for implementation tailored to the current context and the characteristics of the industry. Some authors argue that Lean implementation in industry depends on mental complexity, dynamism, contextual factors, and relationships between suppliers and/or customers (Shah & Ward, 2003; So & Sun, 2010; Azadegan et al., 2013). Therefore, there is a strong need to address the importance of assessing the maturity level of Lean implementation.

Researchers Chiera et al. (2021) emphasize that assessing the level of Lean maturity is important, as it allows quantifying the efficiency and effectiveness of the company's activities and also evaluating its performance levels. Researchers Karlsson & Åhlström (1996) define Lean as the sum of four major perspectives: "lean development", "lean manufacturing", "lean acquisition" and "lean distribution", and in this sense they developed a model to evaluate the leanness index evolution of Lean implementation. Conversely, researchers Welo & Ringen (2015) developed a model for assessing the level of Lean maturity consisting of six key indicators, such as: "transmission of value to the customer", "transmission of knowledge", "standardization", "consolidation", "continuous improvement" and "promotion of Lean culture".

Assessing Lean maturity is more than a diagnostic exercise, it serves as a strategic instrument that enables SMEs to fully realize the benefits of Lean by ensuring that practices are clearly understood, effectively implemented, and continuously refined. This evaluation process is essential for SMEs striving to achieve sustainable operational excellence and long-term competitiveness (Chong & Perumal, 2022). In 2022, manufacturing SMEs represented only 8.5% of all SMEs; however, they accounted for 18% of total SME employment and

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contributed 19% to the overall value added by SMEs in the EU-27 non-financial business sector, highlighting the importance and need to implement Lean practices (Di Bella et al., 2023). However, there are still some gaps in the methodology used to assess the maturity levels of Lean implementation in SMEs, causing a delay in understanding companies' current performance.

Common reasons for Lean implementation by companies include cost reduction, increased profits, visible organizational improvement on the shop floor, and achieving a competitive position (Zhou, 2016). Lean implementation frameworks and roadmaps exist, but there is a need for a more comprehensive and systematic roadmap, considering cultural and leadership dimensions, to ensure success (Mamoojee-Khatib et al., 2025). While various studies assess the degree of Lean implementation, understanding trends in research and investigations on these topics is necessary.

Various studies, including those by Karlsson & Åhlström (1998), Womack & Jones (2003), Karim & Arif-Uz-Zaman (2013), and Maasouman & Demirli (2016), have proposed models. However, the majority of these models are rooted in the experiences of large enterprises, which limits their applicability to SMEs. Yusof & Aspinwall (2000) argued that SMEs cannot simply mimic examples from large companies but must adapt them to their own reality. Many companies choose to implement Lean for its numerous benefits and, after gaining some experience, aim to assess their Lean maturity level to understand how much progress they have made since implementation (Goldratt, 2009; Liker, 2021). This assessment is crucial as initial operational performance may appear slow but tends to advance quickly until higher maturity levels stabilize (Santos Bento & Tontini, 2018). Lean manufacturing maturity is a prerequisite for Industry 4.0 in SMEs (Tsukada et al., 2024).

Srinivasaraghavan & Allada (2006), measuring Lean maturity is essential because companies implementing Lean need a clear and well-defined direction to guide their efforts, which can explain 49.9% of the variation in operational performance (Santos Bento & Tontini, 2018). Jørgensen et al. (2007) define maturity as the level of development of a company's Lean capabilities towards a state of long-term sustainability. Santos Bento & Tontini (2018) defined maturity as the degree to which a process is distinctly delineated, quantified, regulated and described through successive phases.

Galeazzo (2021) relates Lean maturity in companies to years of implementation, experience, and the use of Lean tools. Assessing progress in Lean implementation in companies through the measurement of maturity is important, contributing to companies' ability to evaluate their current implementation state and compare with others in the process of Lean implementation (e Silva et al., 2024). However, several published articles have suggested tools for assessing Lean maturity, emphasizing the role of Lean practices and tools in achieving the main objectives of Lean management systems. The Lean philosophy aims to minimize lead time by eliminating waste and increasing process value (Sisson & Elshennawy, 2015; Taş, 2024). Similarly, Kumar et al. (2024) defines Lean as a methodology focused on reducing waste, creating value stream maps and identifying non-value-added activities.

Although several models for Lean maturity assessment have been proposed in the literature, few studies critically compare their scope, structure, and applicability. For instance, the model by Karlsson & Åhlström (1996) adopts a multidimensional approach but is primarily designed for large industrial settings, limiting its relevance for SMEs. In contrast, the framework proposed by Welo & Ringen (2015) includes qualitative indicators such as “value delivery” and “Lean culture promotion”, making it more adaptable to less formalized organizations. Santos Bento & Tontini (2018) model demonstrates a strong correlation between maturity and operational performance but requires extensive instrumentation and data collection, which may pose barriers for resource-constrained SMEs. These differences highlight that no single model is universally applicable. As such, future research should prioritize developing or adapting hybrid approaches combining quantitative and qualitative elements, while remaining scalable and accessible for SMEs. Moreover, empirical validation through real-world case studies is crucial to assess these models' practical usability, robustness, and impact in diverse organizational contexts.

The measurement of maturity should follow a scalable structure in levels until the goal is achieved. Based on this information, it is understood that assessing Lean maturity levels is important for companies to decide to become Lean. The existing literature still lacks future research on assessment models for the level of Lean implementation and companies' knowledge about their current state of Lean applications and expertise.

Despite the various Lean maturity assessment models proposed in the literature, the field remains fragmented and lacks methodological convergence. Most models are derived from large enterprise contexts and often fail to account for SMEs unique structural and operational characteristics. There is a notable imbalance between studies focusing solely on quantitative indicators and others adopting qualitative or cultural approaches, with few attempting an integrated view. Additionally, the absence of longitudinal validation limits understanding of how Lean maturity evolves. Contextual dimensions such as sectoral variation, digital readiness, and regional industrial dynamics are also underexplored. These gaps highlight the need for flexible, empirically grounded models that address the specific challenges of SMEs and offer both diagnostic and developmental value. A more critical and comparative research agenda is needed to consolidate existing approaches and guide future model development.

2. METHODS

2.1. Data

This research addresses a bibliometric analysis using bibliometric data to assess the Lean maturity level in SMEs. First, data were collected from two platforms, Web of Science (WoS) and SciVerse Scopus (Scopus), covering articles published between 2010 and 2024. These platforms are widely recognized for their reliability, extensive content, and global reach, ensuring the credibility of the analysis (Alryalat et al., 2019).

Next, a detailed bibliographic review was carried out, focusing on the different tools for assessing the level of Lean maturity in SMEs and the principal authors who have researched this topic. Finally, the collected data were processed, analyzed, and discussed. The VOSviewer software (version 1.6.18) (Van & Waltman, 2018) and the Bibliometrix R package from R Studio (Aria &

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Cuccurullo, 2017) were used for data analysis. These allow the creation of bibliometric maps and enable more straightforward interpretation, regardless of the size of the data obtained (Castillo-Vergara et al., 2018; Mas-Tur et al., 2021).
Bibliometric analysis identifies key themes, trends, and relevant journals (Treinta et al., 2014), which are appropriate for this research focused on assessing the maturity levels of Lean implementation. This analysis is widely used in scientific research to evaluate trends and position relevant studies within this topic (Zupic & Čater, 2015; Xiao & Watson, 2019).
These types of analyses are increasingly popular for their ability to objectively analyze patterns in scientific research, offering different perspectives and trends on the impact within a domain (Hood & Wilson, 2001; Du & Teixeira, 2012). The Pritchard (1969) model, bibliometric analysis applies mathematical and statistical methods to evaluate research results and their influence in a specific area.
Metadata from the selected articles was analyzed using VOSviewer and Bibliometrix, providing insights into publication trends, including the number of publications per year, visualized through graphs generated in Microsoft Excel.

2.2. Methods

This study adopts a bibliometric scoping review design, combining quantitative mapping techniques with a structured review process. The PRISMA-ScR protocol was followed to enhance methodological rigor and transparency. This framework is widely recognized in the academic community for ensuring clarity, replicability, and comprehensiveness in scoping reviews. PRISMA-ScR supports the systematic identification, selection, and synthesis of relevant literature, which is especially pertinent given the fragmented and multidisciplinary nature of research on Lean maturity in SMEs.
As previously noted, the phases of bibliometric analysis, adapted from Zupic & Čater (2015), include the following steps: (1) study design, which involves setting the research objective, selecting the database, and defining the filters to narrow the sample; (2) data collection and processing, encompassing the selection, capture, and processing of bibliometric data following the applied filters from the design phase; (3) data analysis, where software is used to perform bibliometric analyses; and (4) interpretation, where findings are examined and explained. Figure 1 presents the procedural sequence used to achieve the results.
The sample was gathered through the following steps:

- Setting the research timeframe (2010-2024);
- Identifying search keywords;
- Selecting relevant scientific articles;
- Performing bibliographic searches on WoS and Scopus platforms;
- Bibliometric evaluation using data collected from various databases;
- Using VOSviewer and Bibliometrix software to create visualizations;
- Select the most influential authors and the most significant themes;
- Interpret and analyze the results.

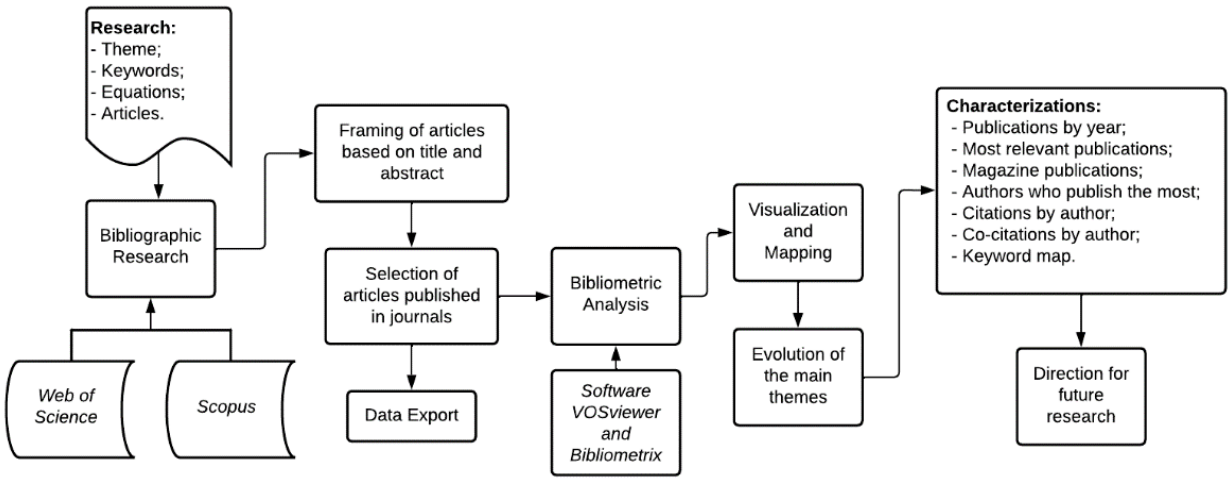

Figure 1 - Diagram of the research methodology and bibliometric analysis process (Guimarães et al., 2025).

3.3. Sample

The time frame from 2010 to 2024 was deliberately selected to capture the most relevant and recent developments in Lean maturity assessment in SMEs. This period covers the last 15 years and reflects the growing academic and practical interest in Lean practices under the influence of digitalization, Industry 4.0, and organizational transformation trends. Including publications up to 2024 allows the analysis to incorporate the latest available studies, ensuring that the findings reflect current research directions and technological contexts.
The terms “Leanness” and “Level of Maturity” used in this research were employed by several authors, including Soriano-Meier & Forrester (2002), Vinodh & Dinesh Kumar (2012), Darestani & Shamami (2019).
As detailed in Table I, several terms were combined with specific search equations, resulting in Search 1 for the WoS database and Search 2 for the Scopus database. The methodological framework used in this bibliometric study was developed through a structured diagram, incorporating the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analysis for Scoping Reviews) guidelines (Tricco et al., 2018, Donthu et al., 2021).

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Table 1 - The bibliometric analysis process based on the PRISMA-ScR framework.

Step 1. Aims and the extent of the bibliometric investigation					
A thorough examination of research trends, output, and collaborative efforts to identify developments, gather findings within the Lean context, and evaluate its level of maturity.					
RQ1. What is the current trajectory of scientific productivity in Lean methodologies and the evaluation of maturity levels? RQ2. What is the structure of the collaborative research network in this field? RQ3. What are the key patterns defining the search trends in this area?					
Step 2. Selecting the methods for conducting bibliometric analysis					
Academic databases: WoS and Scopus; **Tools for bibliometric mapping:** VOSviewer and Bibliometrix					
Step 3. Gathering data for the bibliometric analysis.					
Keywords (*Web of Science*)					
	TS="lean manufacturing"		**TS="lean maturity model"**	**TS="industrial SMEs"**	**Results**
Search 1	OR TS="lean production" OR TS="lean management" OR TS="lean tools" OR TS="lean culture" OR TS="lean adoption" OR TS="lean philosophy" OR TS="lean methods" OR TS="lean sustainability" OR TS="lean green" OR TS="Toyota production system" OR TS="lean enterprise") OR TS="lean Six Sigma" OR TS="lean principles"	AND	OR TS="lean maturity" OR TS="lean maturity level" OR TS="maturity model" OR TS="digital readiness" OR TS="lean implementation" OR TS="lean implementation level" OR TS="lean implementation initiatives" OR TS="implementation framework" OR TS="framework" OR TS="leanness" OR TS="lean capability model" OR TS="lean capacity model" OR TS="lean maturity assessment" OR TS="maturity degrees" OR TS="measurement of maturity" OR TS="evaluation of Lean processes" OR TS="lean enterprise self-assessment"	AND	OR TS="evaluation model" OR TS="region" OR TS="small and medium-sized enterprises" OR TS="dimensions"	**241**
Keywords (*Scopus*)					
	TITLE-ABS-KEY "lean manufacturing"		**TITLE-ABS-KEY "lean maturity model"**	**TITLE-ABS-KEY "industrial SMEs"**	**Results**
Search 1	OR "lean production" OR "lean management" OR "lean tools" OR "lean culture" OR "lean adoption" OR "lean philosophy" OR "lean methods" OR "lean sustainability" OR "lean green" OR "Toyota production system" OR "lean enterprise" OR "lean Six Sigma" OR "lean principles")	AND	OR "lean maturity" OR "lean maturity level" OR "maturity model" OR "digital readiness" OR "lean implementation" OR "lean implementation level" OR "lean implementation initiatives" OR "implementation framework" OR "framework" OR "leanness" OR "lean capability model" OR "lean capacity model" OR "lean maturity assessment" OR "maturity degrees" OR "measurement of maturity" OR "evaluation of Lean processes" OR "lean enterprise self-assessment"	AND	OR "evaluation model" OR "region" OR "small and medium-sized enterprises" OR "dimensions"	**367**
	Step 4. PRISMA-ScR flow diagram				**WoS** / **Scopus**
Identification	Registration of all fields obtained by the search in the database.				241 / 367
	Total articles identified.				608
Screening	Articles after filter application (English; 2010 to 2024).				173 / 217
	Total articles after applying the inclusion and exclusion criteria.				390
Eligibility	Deletion of articles manually by title, abstract and keywords.				96 / 136
	Deletion of duplicate articles.				74
Included	Included in the analysis.				19 / 65
Overall	Final sample.				**84**
Step 5. Running the bibliometric analysis					
Assessment of performance	Providing an overview of key research performance metrics, such as publication and citation numbers, including the publication rate classified by journal, research field, author, institution, and country.				
Scientific mapping	Illustration of the intellectual structure through citation and co-authorship analysis, while investigating research themes and topics using co-citation analysis, bibliographic coupling, and keyword co-occurrence analysis.				
Step 6. Recommendations and potential impacts for future inquiries					
Step 7. Conclusions					

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The exclusion criteria were applied in two sequential phases. First, articles were removed if their titles, abstracts, or keywords revealed that they did not directly address Lean maturity assessment, focused solely on large enterprises, or did not present methodological or conceptual contributions relevant to SMEs. Secondly, duplicated articles retrieved from both WoS and Scopus databases were excluded. Additional filters included language (only English-language publications were considered) and publication type (only peer-reviewed journal articles were selected, excluding conference papers, reviews, and book chapters). After these steps, only studies that explicitly addressed Lean maturity or implementation levels within the SME context were retained.

This bibliometric study analyzed 241 articles from Web of Science (WoS, 2024) and 367 from Scopus (Scopus, 2024), focusing on Lean practices, maturity levels and relevant literature. These publications have helped identify critical studies, influential authors and emerging trends, providing insights into the development of SMEs. Some countries have shown a growing interest in Lean practices, highlighting its relevance as a relatively recent topic. This study contributes by consolidating the existing literature and creating a basis for future research.

Keywords such as “Lean Manufacturing”, “Lean Maturity Model” and “Industrial SMEs” were combined in the searches. The results from WoS and Scopus (Search 1 and Search 2) were exported and organized into fields such as author names, titles, publication years, sources, citations, abstracts, keywords, and document types.

In the first phase, 232 publications were excluded through analysis of titles, abstracts and keywords. During the second phase, 74 duplicate posts were removed. After exclusions in the final phase, 19 and 65 publications from WoS and Scopus were included, respectively. Of the 390 initial articles, 84 were selected as relevant and used in this research.

4. RESULTS

4.1. Bibliometric Analysis

This section contains the bibliometric analysis employing specific techniques for measuring the indices of production and dissemination of scientific knowledge related to studies on Lean and Lean maturity in SMEs. The analysis aims to examine scientific production in a particular field of knowledge and highlight some existing issues to be investigated in future research (Caviggioli & Ughetto, 2019). It seeks to enhance understanding of published articles related to Lean and maturity level measurement tools through co-citation maps, co-occurrences, most cited articles, and most cited authors, using these data to demonstrate research trends.

The next part of the article reveals the results from bibliometrics on the 84 selected articles, following the PRISMA-ScR flow methodology for selection and filtering. These works were scrutinized and found to be valuable in addressing the research questions of this article. A bibliometric analysis was carried out to identify the number of publications and the journals in which they appear.

4.1.1. Year of Published

Figure 2 illustrates a progressive increase in scientific publications addressing Lean maturity in SMEs, particularly from 2015 onwards. The peak observed in 2022, with 16 publications, indicates growing academic interest, likely influenced by the rising importance of operational excellence, digital transformation, and competitiveness in small business contexts. This trend underscores a research momentum that aligns with global industry shifts and policy support for SME innovation.

The research in the WoS and Scopus databases from 2010 to 2024 shows an upward trend in publications reflecting a growing recognition of the importance of assessing Lean maturity in SMEs. This increase suggests a shift in focus from generic Lean adoption to more structured and measurable maturity models. The increase in recent years may also be associated with the influence of Industry 4.0 and the need to integrate Lean with digital transformation, leading researchers to reevaluate traditional structures.

The initial bibliometric analysis conducted on the portfolio of 84 articles involves mapping the publications over a time interval. This entails counting how many articles were published each year, where the number of articles is shown on the Y axis, and the time frame is presented on the X axis.

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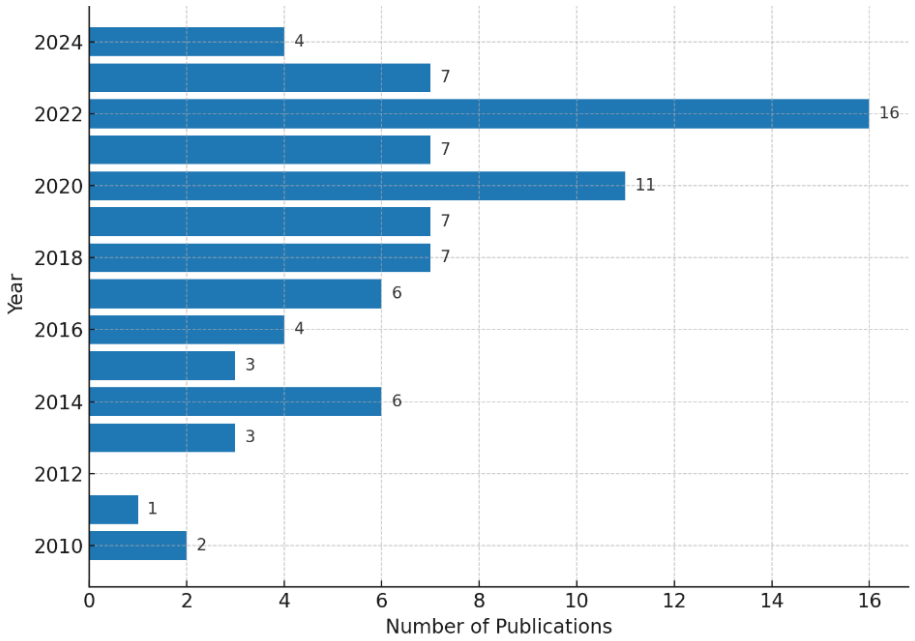

Figure 2 - Annual Growth in Scientific Publications on Lean Maturity in SMEs (2010–2024).

4.1.2. Distribution of the most cited publications by countries

Figures 3 and 4 reveal that countries such as India and Brazil are leading contributors, suggesting that Lean maturity research is increasingly relevant in emerging economies where SMEs face resource and productivity constraints. In these contexts, SMEs often operate under significant resource constraints and face persistent productivity challenges. This underscores the importance of developing customized Lean maturity models that account for contextual factors, such as informal management structures, limited technological infrastructure, and varying levels of access to automation and digital tools.

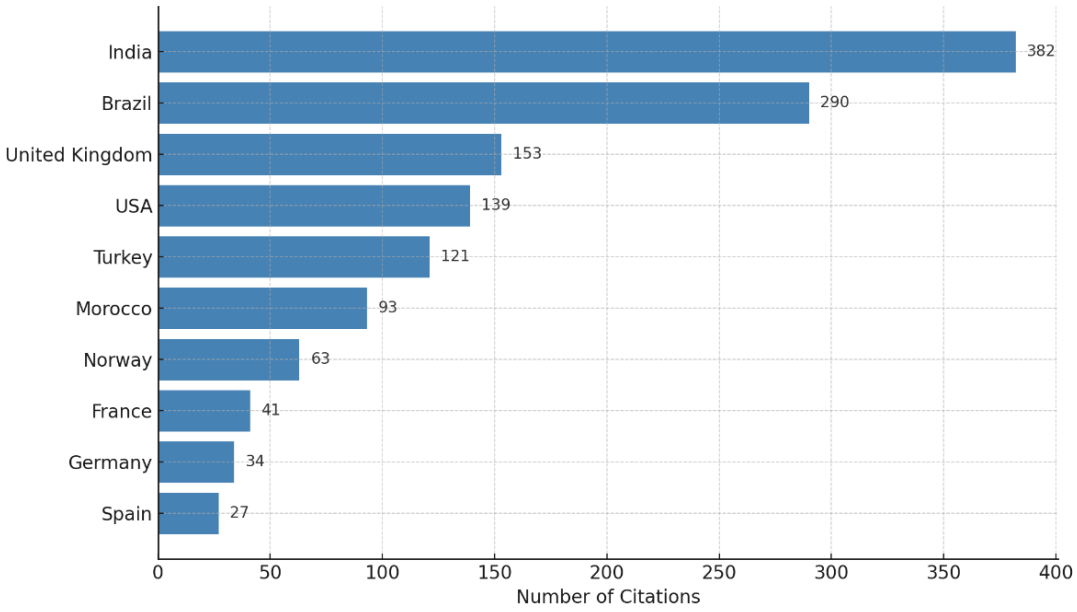

Figure 3 - Scientific Publications by Country: Top Contributors to Lean Maturity Research.

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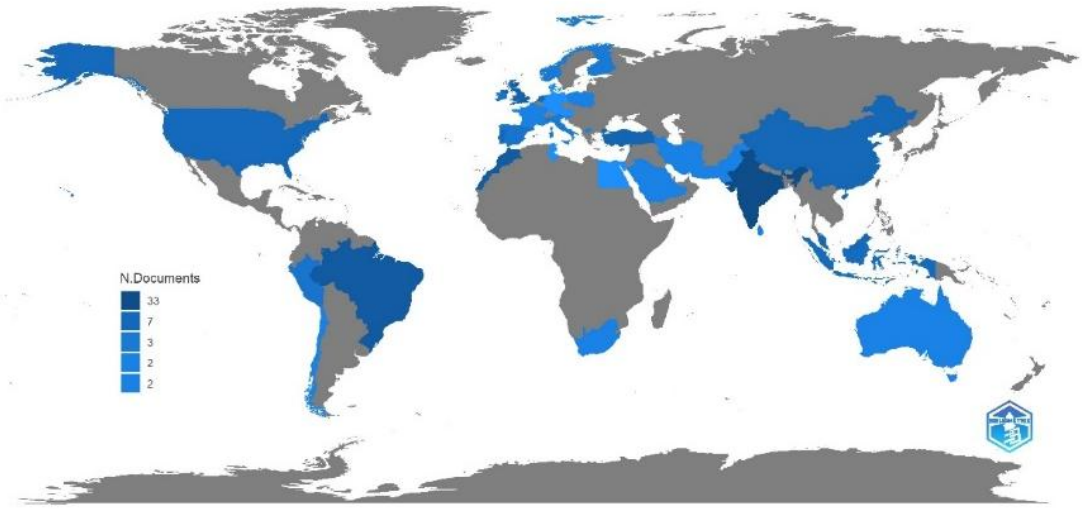

Figure 4 - Map of Scientific Production by Country on Lean Maturity (2010–2024).

4.1.3. Type of Journal

Figure 5 identifies the journals with the highest publication output. The concentration of studies in a few journals suggests that Lean maturity remains a niche topic, primarily addressed within operations and quality management domains. This reveals an opportunity for broader interdisciplinary dissemination, particularly in digital innovation and SME strategy fields. It is worth noting that this analysis exclusively considers articles published in academic journals. The impact of these journals within their respective scientific fields can be assessed by reviewing their impact factors, as provided in the databases.

Prominent journals contributing the most to this topic include: “International Journal of Lean Six Sigma”, “Total Quality Management and Business Excellence”, “International Journal of Production Research”, “Journal of Manufacturing Technology Management”, “Production Planning and Control”, and “International Journal of Productivity and Performance Management”.

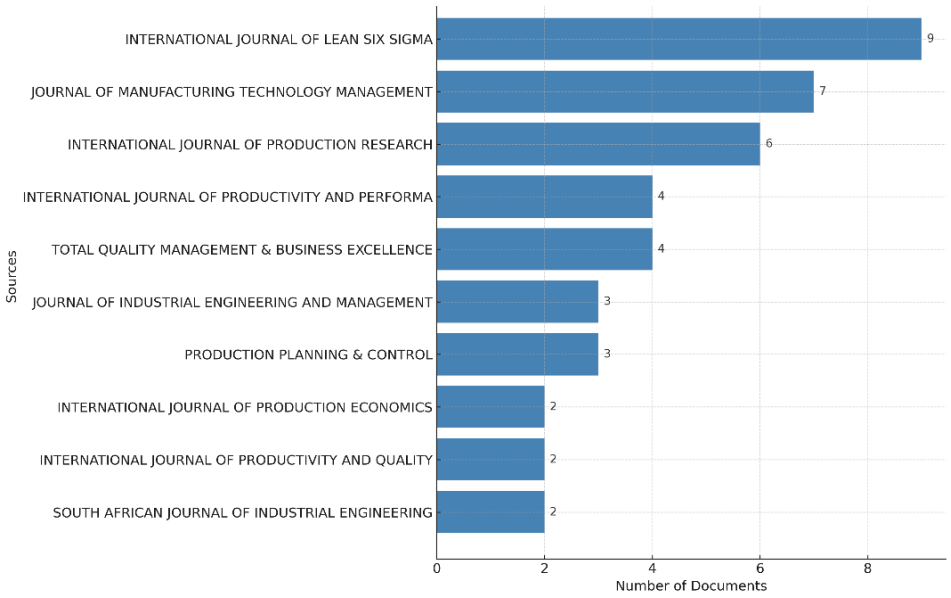

Figure 5 - Top cited articles on Lean Maturity in SMEs, categorized by journal.

In Figure 6, it is possible to observe the growth of publications by journals over the last few years. The concentration of publications in a small number of journals suggests that Lean maturity research remains a niche topic within operations and quality management. This highlights the importance of increasing interdisciplinary dialogue, especially with journals focused on digital transformation, innovation, and SME competitiveness, where Lean maturity could be further explored in integrated frameworks.

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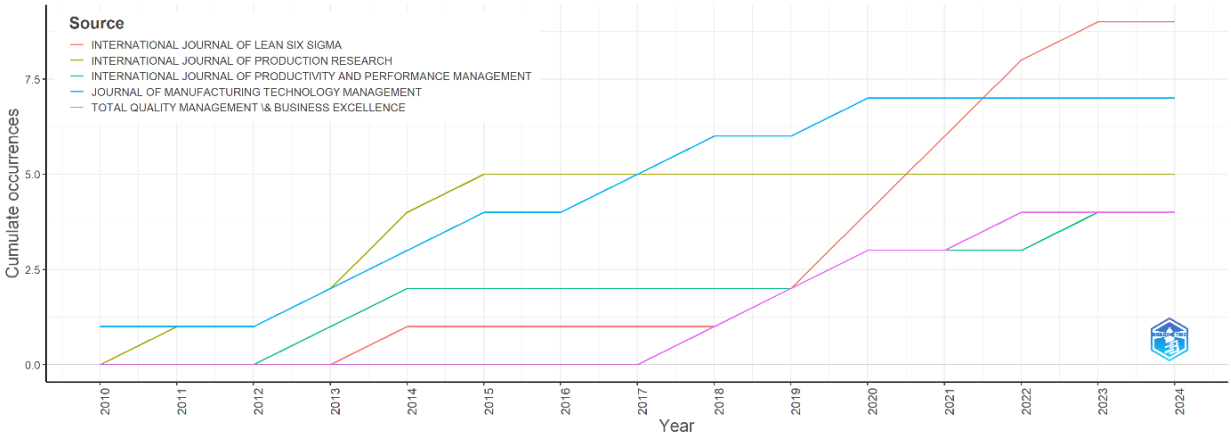

Figure 6 - Journals featuring the most significant articles published in recent years (2010-2024).

4.1.4. The most significant publications from recent years.

Table II highlights the foundational studies most frequently cited by other researchers in the field. The ranking of these publications was established based on citation analysis from the WoS and Scopus databases. Each article was thoroughly reviewed to ensure its relevance to the topic of this study. The final list includes the 26 most significant articles from recent years that address the assessment of Lean maturity levels in SMEs.

Table 2 - The most impactful publications from the past few years (2010-2024).

Ranking	Author	Title	Year	Citation
1	Zhou, 2016	"Lean principles, practices, and impacts: a study on small and medium-sized enterprises (SMEs)"	2016	542
2	Pakdil & Leonard, 2014	"Criteria for a lean organisation: Development of a lean assessment tool"	2014	371
3	Ghosh, 2013	"Lean manufacturing performance in Indian manufacturing plants"	2013	344
4	Saurin et al., 2011	"A framework for assessing the use of lean production practices in manufacturing cells"	2011	256
5	Forrester et al., 2010	"Lean production, market share and value creation in the agricultural machinery sector in Brazil"	2010	155
6	Cezar Lucato et al., 2014	"Performance evaluation of lean manufacturing implementation in Brazil"	2014	132
7	Santos Bento & Tontini, 2018	"Developing an instrument to measure lean manufacturing maturity and its relationship with operational performance"	2018	127
8	Belhadi et al., 2016	"A Framework for Effective Implementation of Lean Production in Small and Medium-sized Enterprises"	2016	111
9	Gupta et al., 2013	"A strategic and operational approach to assess the lean performance in radial tyre manufacturing in India: A case based study"	2013	110
10	Tortorella et al., 2015	"Learning organisation and human resources management practices: an exploratory research in medium-sized enterprises undergoing a lean implementation"	2015	85
11	Belhadi et al., 2018	"Lean production in SMEs: literature review and reflection on future challenges"	2018	82
12	Taherimashhadi & Ribas, 2018	"A model to align organizational culture to lean culture"	2018	72
13	Mohammad & Oduoza, 2020	"Lean-excellence business management for manufacturing SMEs focusing on KRI"	2020	54
14	Brito et al., 2019	"A continuous improvement assessment tool, considering lean, safety and ergonomics"	2019	49
15	Abbes et al., 2022	"New Lean Six Sigma readiness assessment model using fuzzy logic: Case study within clothing industry"	2022	43
16	Bento & Tontini, 2019	"Maturity of lean practices in Brazilian manufacturing companies"	2019	42
17	Ruben et al., 2017	"Performance evaluation of lean sustainable systems using adaptive neuro fuzzy inference system: a case study"	2017	39
18	Agrawal et al., 2017	"Benchmarking fuzzy logic and ANFIS approaches for leanness evaluation in an Indian SME A case study"	2017	32
19	Tayaksi et al., 2020	"A new holistic conceptual framework for leanness assessment"	2020	27
20	Martins et al., 2021	"Lean practices adoption in the portuguese industry"	2021	21
21	Darestani & Shamami, 2019	"Performance evaluation of lean production based on balanced score card method using ANP and SIR: a case from Iranian home appliance industry"	2019	18
22	Amin et al., 2021	"A fuzzy-based leanness evaluation model for manufacturing organisations"	2021	15
23	Baskaran & Lakshmanan, 2019	"A framework for lean readiness evaluation using a hierarchical fuzzy system"	2019	13
24	Chong & Perumal, 2022	"Conceptual Model for Assessing the Lean Manufacturing Implementation Maturity Level in Machinery and Equipment of Small and Medium-sized Enterprises"	2022	10
25	Aripin et al., 2023	"Save it for a rainy day! Lean strategies for cost saving: The role of Lean maturity"	2023	7
26	e Silva et al., 2024	"Lean-circular maturity model (LCMM) for companies' self-assessment in terms of process, product and life cycle thinking"	2024	5

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Articles by Zhou (2016) and Pakdil & Leonard (2014) stand out, indicating their influence in the current understanding of Lean assessment frameworks. However, the dominance of a few works also suggests the need for more updated and context-sensitive models to address emerging challenges, such as digital maturity and sustainability. Furthermore, the geographical concentration of the most cited works, often from specific industrial contexts, may limit the generalizability of the conclusions, reinforcing the need for broader empirical validation in diverse SMEs environments.

Figure 7 shows consistent publication activity over time by leading researchers, such as Antony, Vinodh, and Cudney. Their sustained output suggests the existence of active research clusters dedicated to Lean implementation in SMEs. Nevertheless, the limited overlap in publication periods among other authors indicates a fragmented landscape that may benefit from more collaborative and cross-institutional efforts.

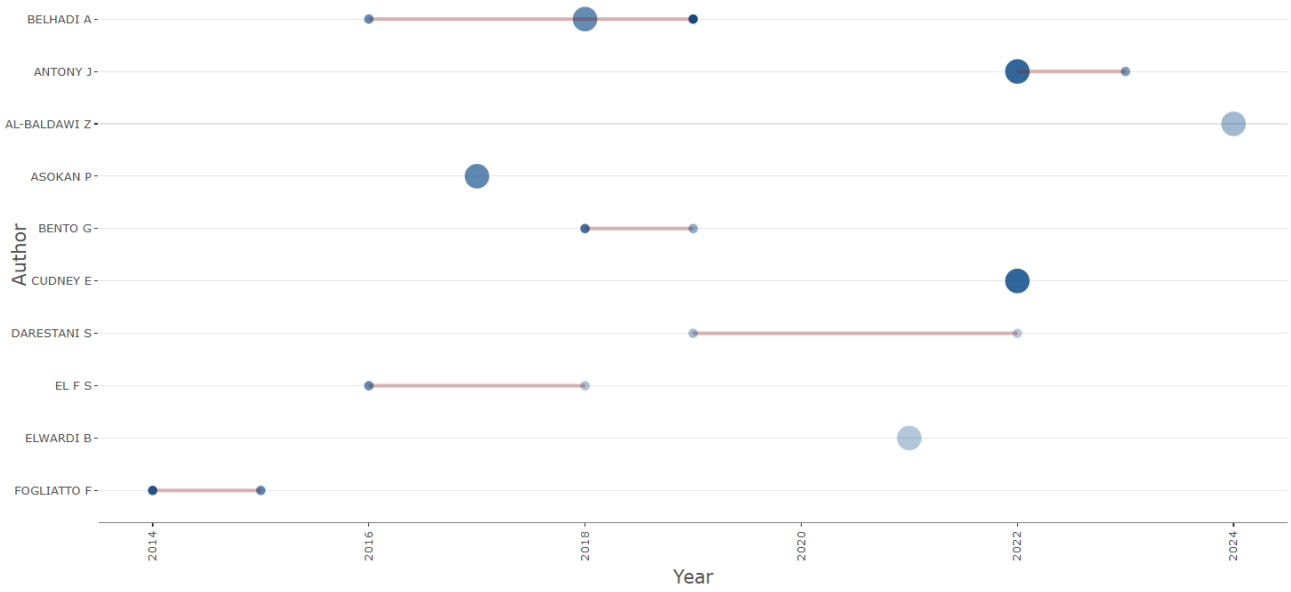

Figure 7 - Timeline of Publications by the Most Prolific Authors.

4.1.5. Analysis of the authors who have published the most

Figure 8 presents the co-authorship network, revealing a low density of collaboration among authors. This fragmentation implies limited coordination across institutions or countries, which may hinder the development of shared frameworks and cumulative knowledge. Encouraging international and cross-sector collaboration could enhance the robustness and applicability of Lean maturity models in diverse SME contexts.

From the obtained results through bibliometric analysis, within a universe of 174 authors, only 126 authors have at least one article cited at least twice, and only 9 authors are interconnected. The authors who publish and study this theme the most include Antony J., Cudney E., Alexander P., Shetty S., Cudney E. A., Barclay R. C., Lameijer B.A., Boer H., and Does R.J., among others. Figure 8 shows the number of publications per author, revealing that authors with the highest number of published articles do not always have the highest citation indices and may not appear in the top 10. Likewise, some authors with fewer publications may have lower citation counts. However, this does not imply that their contributions are insignificant; on the contrary, their work remains highly relevant to this study.

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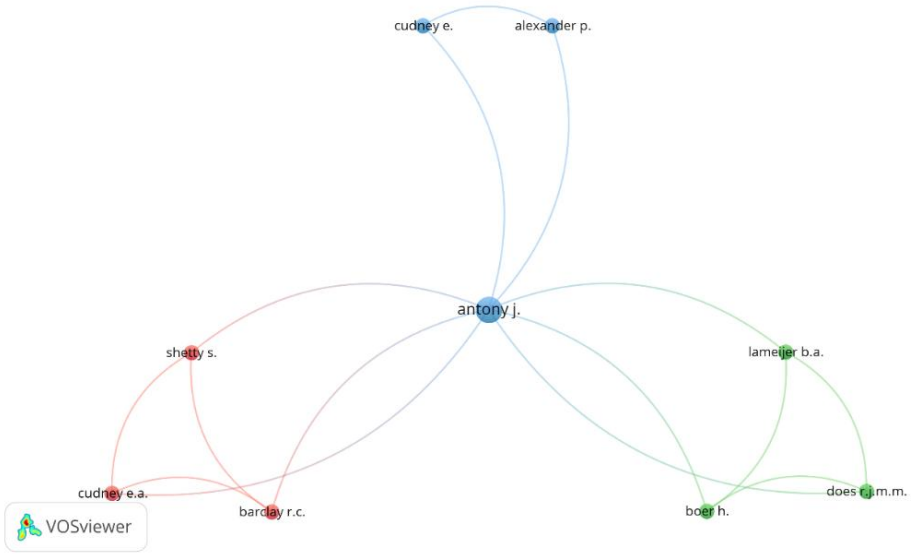

Figure 8 - Network overlay of the most prolific authors, connected to each other, obtained by VOSviewer.

The recurring presence of some authors suggests the existence of influential research groups dedicated to Lean performance in SMEs. However, the limited number of authors interconnected in the co-authorship map reveals a fragmented research landscape. This fragmentation highlights the need to promote broader academic collaboration and consolidation of shared frameworks, which could improve methodological convergence and knowledge transfer in the domain of Lean maturity assessment.

4.1.6. Analysis of co-citations by author

In this analysis, 4650 co-cited authors were identified, each with a minimum of 20 co-citations. In essence, out of the 4650 authors, only 22 are co-cited at least 20 times.

Figure 9 emphasizes the most frequently referenced sources grouped into various co-citation clusters. When these references are cited collectively, they establish a network of citations that reveal shared lines of thought, allowing the identification of key authors in co-cited studies.

Figure 9, created using VOSviewer, highlights three primary clusters, each representing the number of co-citations per author. In the right cluster (green), notable authors with the highest co-citation counts include Shehab, E., Belhadi, A., Jain, R., Achanga, P., and Touriki, F. E., among others. Similarly, the left cluster (red) features authors such as Shah, R., Bhasin, S., Ward, P. T., Jones, D. T., and Womack, J. P., who also show many co-citations. Authors such as Antony, J., Vinodh, S., Kumar, M., and Kodali, R., are prominent in the blue cluster due to their significant co-citation frequency.

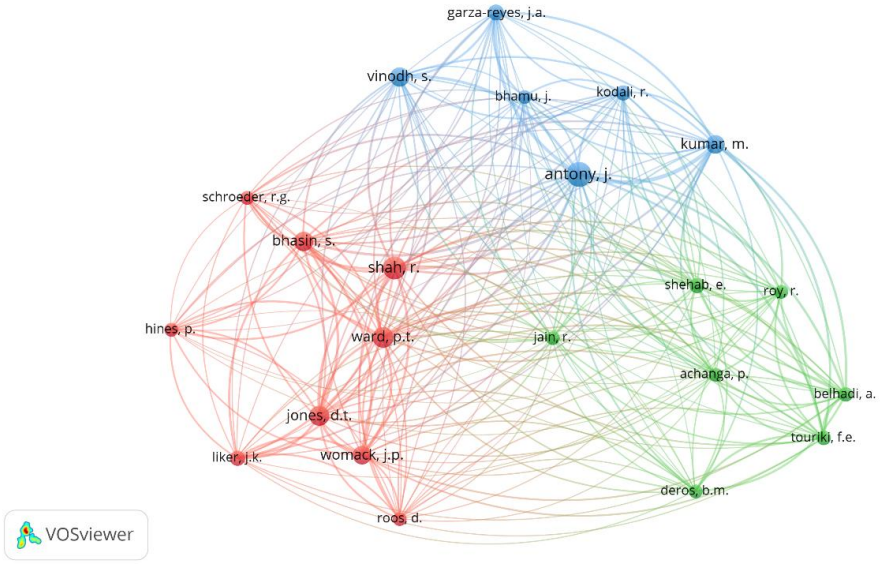

Figure 9 - Cluster-highlighted author co-citation network in lean maturity research (2010–2024) using VOSviewer software.

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The identified clusters show distinct conceptual lineages, with some authors focusing on cultural and human-centric Lean approaches (e.g., Womack; Shah). In contrast, others emphasize quantitative or fuzzy logic models (e.g., Antony, Vinodh). This division suggests a methodological gap that could be bridged by future studies proposing integrated or modular assessment models.

4.1.7. Keyword co-occurrences analysis by author

A co-occurrence map was created using all the keywords from the research data, which combined results from the WoS and Scopus databases. The analysis, conducted with VOSviewer software and Bibliometric R, visually represents the node network within the literature. The database identified 229 commonly used words in titles, abstracts, and keywords, with 45 keywords appearing at least twice. Figure 10 displays the co-occurrence graph, where each circle's size represents the keyword's strength and relevance over recent years.

The connections that these keywords have with each other are illustrated in the links established in the graphs, as well as the relationship between each of them through the clusters that form in the graph. In the co-occurrence analysis, the total strength of the link indicates when the two keywords occur together in the same publication.

The analysis reveals that the most commonly used keywords in the reviewed articles are: “lean manufacturing”, which appears in the majority of publications, followed by terms such as “lean production”, “leanness”, “lean Six Sigma”, “SMEs”, and “lean implementation”.

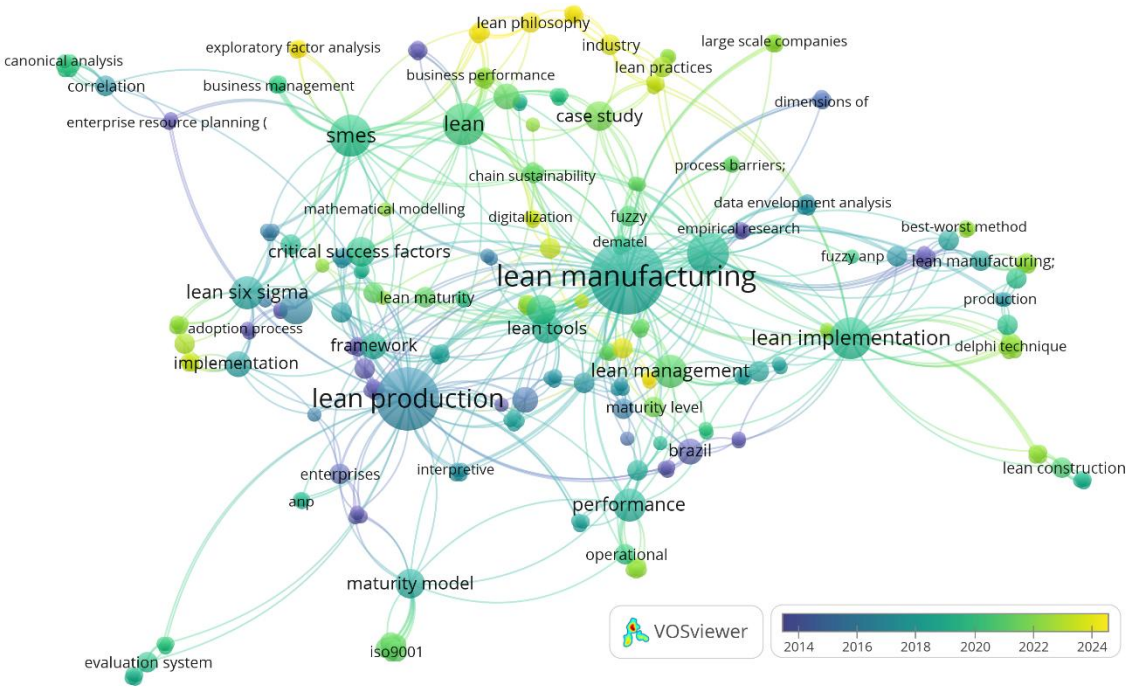

Figure 10 - Co-occurrence Network of Keywords in Lean Maturity Research (2010–2024).

It is still possible to confirm the analyses obtained earlier through the Bibliometrix R software. The most prominent keywords in the articles under study have been included in Figure 11. These keywords were the most used by the authors and helped understand research trends and how clusters formed, with these words connecting them.

The prominence of terms like “lean implementation”, “leanness”, and “lean Six Sigma” suggests that the literature often concentrates on the initial phases of Lean transformation, focusing on tool adoption and implementation strategies. However, there is limited emphasis on post-implementation monitoring, performance evolution, or long-term sustainability of Lean practices. Furthermore, the relative scarcity of keywords related to digitalization, smart manufacturing, or environmental sustainability indicates emerging yet underexplored areas. Future research could benefit from expanding the keyword landscape to include themes aligned with Industry 4.0, green Lean, and digital maturity.

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Figure 11 - The keyword map was obtained using the Bibliometrix R software.

4.2. Practical recommendations for SMEs managers

Based on the bibliometric findings and the prominent trends identified in the literature, some concrete and actionable recommendations can be proposed to support SMEs managers in implementing or evaluating Lean practices. A sensible starting point is the adoption of scalable and straightforward maturity models that emphasise key Lean principles such as waste reduction, process standardisation, and the delivery of customer value. In the absence of external consultancy, SMEs can benefit from using self-assessment tools to periodically monitor the adoption and evolution of Lean practices, enabling the identification of improvement areas. Furthermore, promoting a Lean organisational culture, through investment in employee training, cross-functional communication, and leadership involvement, emerges in the literature as a consistent enabler of successful transformation. Lastly, progressively integrating digital technologies into Lean processes can enhance data collection, workflow visibility, and performance tracking. This alignment reinforces operational efficiency and positions SMEs to transition more effectively into Industry 4.0 environments.

CONCLUSION

The results have demonstrated that research in Lean principles and the assessment of Lean maturity levels in SMEs has grown significantly in recent years, with a tendency to continue increasing. Using VOSviewer and R Studio's Bibliometric R software, bibliometric analysis aided in creating maps and extracting information from the WoS and Scopus databases. This process led to the construction of various networks, including those of scientific publications, relevant journals, highly cited authors, and commonly used keywords.

The findings indicate that the literature in this domain is relatively recent and has been undergoing exponential expansion, with a trajectory likely to persist. Bibliometric analysis further revealed an increasing focus on the impact of strategy adoption by companies, emphasizing innovation in business models, global value chains, collaboration, and performance.

This study considered the selection of publications assessing Lean maturity levels in SMEs to be highly pertinent. Future research should explore the relationships between various models to evaluate Lean maturity levels in the literature and understand their impact on SME performance. Additionally, conducting bibliometric analyses with other reference databases would be essential for a more comprehensive understanding.

Moreover, future studies would benefit from integrating real-world case studies to bridge the gap between bibliometric data and practical applications. Future research should explore the empirical validation of hybrid maturity models that combine qualitative (cultural and behavioral indicators) and quantitative metrics. Studies comparing the applicability of existing models across sectors (e.g., manufacturing vs. services) or regions would help refine their adaptability. Moreover, longitudinal case studies could reveal how maturity levels evolve, providing valuable insights for dynamic Lean implementation in SMEs. Finally, research integrating digital readiness with Lean maturity assessments could support the transition to Industry 4.0 in small enterprises.

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AUTHOR'S CONTRIBUTION

Conceptualization, A.G., P.R. and A.J.M.C.; data curation, A.G; formal analysis, A.G., P.R. and A.J.M.C.; investigation, A.G.; methodology, A.G.; supervision, P.R. and A.J.M.C.; validation, P.R. and A.J.M.C.; writing-original draft, A.G.; writing-review and editing, P.R. and A.J.M.C.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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