Mapping Lean Six Sigma Research: Advancing Sustainability through Bibliometrics

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Abstract

Purpose: This paper examines the global evolution of Lean Six Sigma research and its role in advancing sustainable practices. Maps the intellectual structure, thematic trends, and collaborative networks, highlighting its alignment with the United Nations Sustainable Development Goals.

Design/methodology/approach: A bibliometric analysis is conducted using Scopus database, covering 2,148 peer-reviewed publications up to 2025. Performance indicators and science mapping techniques, including co-authorship, co-occurrence, and overlay visualizations, are applied through Bibliometrix and VOSviewer to identify influential scholars, institutions, countries, and thematic clusters.

Findings: United States, India, and United Kingdom emerge as leading contributors, with Jiju Antony as the most prolific scholar. Thematic clusters are identified: one emphasizing industrial efficiency, sustainability, and digital transformation, and another focused on organizational management, service quality, and healthcare. Trends indicate a shift from traditional process standardization toward integration with Industry 4.0, big data analytics, and sustainability-driven practices.

Practical implications: LSS acts as a strategic enabler of operational excellence and sustainable development, guiding practitioners in manufacturing, healthcare, and services.

Social implications: LSS supports SDG 9, SDG 12, and SDG 3 by enhancing efficiency, resilience, and quality of life.

Originality/value: This is the first comprehensive bibliometric mapping of LSS and sustainability, offering a foundation for global cross-sectoral applications.

Keywords:

Lean Six Sigma, bibliometric analysis, sustainability, Industry 4.0, healthcare quality, global collaboration, thematic evolution.

Plain Language Summary

Lean Six Sigma (LSS) is a widely used approach that helps organizations improve efficiency, reduce waste, and enhance quality. Originally designed for manufacturing, it is now applied in many fields, including healthcare, education, logistics, and government services. Despite its popularity, there has been limited understanding of how research on LSS has developed worldwide over time.

This study analyzed more than 2,000 research articles from the Scopus database to map the growth and direction of LSS research. By using bibliometric methods, the study identified the countries, institutions, and authors that contributed most to the field, as well as the major themes and emerging topics. The findings showed that the United States, India, and the United Kingdom were the main leaders in research output, supported by strong international collaboration. Traditional topics like quality management and process control remained important, while new themes such as sustainability, healthcare improvement, and digital transformation became increasingly prominent.

These results provide valuable insights for both researchers and practitioners. They highlight how LSS continues to evolve as a global framework that supports operational excellence, sustainability, and innovation across industries and societies.

(3335 words)

Introduction

Lean Six Sigma (LSS) became a cornerstone methodology for enhancing quality, operational efficiency, and organizational excellence across diverse industries. Originally rooted in manufacturing, LSS integrated Lean principles, which emphasized waste elimination, with Six Sigma, which focused on defect reduction, to deliver measurable performance improvements. Over the past two decades, its application expanded into healthcare, education, logistics, public services, and government, underscoring its adaptability and the growing global demand for structured, data-driven strategies that advanced both operational excellence and sustainability (Sony and Naik, 2020).

The academic development of LSS mirrored its industrial expansion. Research output increased substantially, particularly in the United States, India, and the United Kingdom, where scholars such as Jiju Antony shaped discourse on critical success factors, organizational readiness, and cross-sectoral applications (Antony *et al*., 2020). Institutions such as Heriot-Watt University and the Mayo Clinic emerged as leading hubs of both theoretical advancement and applied research, especially in healthcare quality improvement.

Thematic studies demonstrated continuity in core topics—total quality management, lean production, and Six Sigma while highlighting a shift toward agile practices, Industry 4.0 integration, and human-centered improvement (Tortorella *et al*., 2021). Keyword analyses further emphasized sustainability and service contexts, where human factors were increasingly central (Donthu *et al*., 2021). Despite these advances, comprehensive global bibliometric perspectives that integrated productivity, thematic evolution, and collaboration

remained limited. This study addressed that gap by mapping the intellectual structure of LSS, identifying leading contributors and thematic developments, and examining its alignment with sustainable practices. Prior reviews of sustainable LSS frameworks underscored the fragmented state of current knowledge (Formigoni Carvalho Walter *et al*., 2021). More recently, this transition was described as Lean Six Sigma 4.0, reflecting its adaptation to digital transformation challenges (Citybabu and Yamini, 2023).
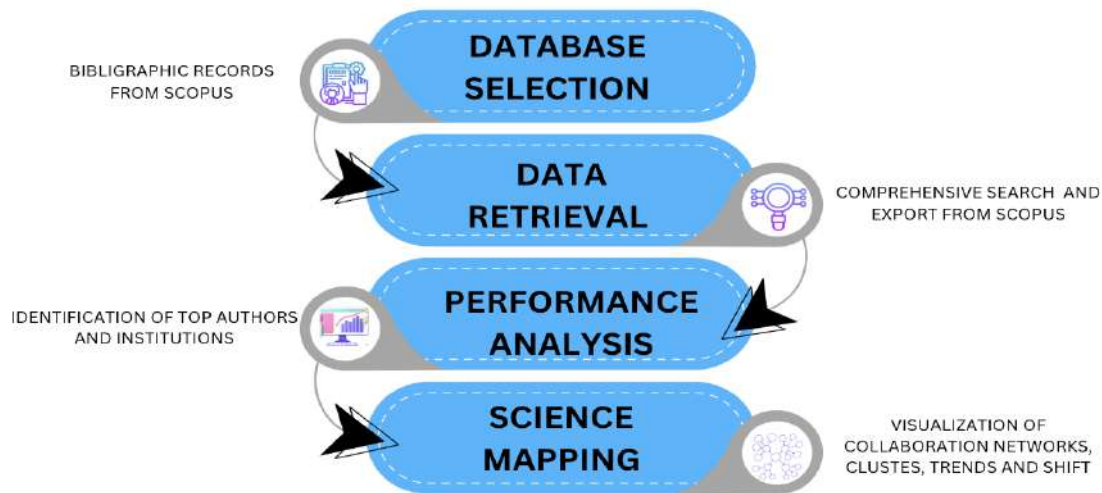
Methods

This study adopted a bibliometric analysis to systematically examine the global evolution of Lean Six Sigma (LSS) research and its intersections with sustainable quality practices. Bibliometric analysis was a well-established quantitative method that enabled researchers to map the intellectual, thematic, and collaborative structures of a field through the statistical evaluation of publication and citation data (Donthu *et al*., 2021). By combining performance analysis and science mapping techniques, the approach not only identified prolific authors, institutions, and countries but also revealed thematic clusters, keyword trends, and the temporal progression of research topics.

The dataset was extracted from the Scopus database on August 8, 2025, yielding 2,148 results. Scopus was selected for its comprehensive indexing of peer-reviewed literature in management, engineering, and applied sciences. The search strategy targeted publications related to Lean Six Sigma and associated quality improvement methodologies, without restrictions on sector or geographic location, thereby ensuring a broad representation of scholarly contributions.

This bibliometric design allowed for both descriptive and relational insights, aligning with the study's aim to provide a global, longitudinal, and thematic overview of LSS research. By situating the findings within broader industrial and societal contexts, the analysis not only quantified research activity but also uncovered evolving priorities and collaborative patterns that shaped the field's trajectory.

Data analysis was conducted using a combination of R's Bibliometrix package and VOSviewer software. Bibliometrix generated statistical summaries such as annual scientific production, author productivity, and citation impact, while VOSviewer facilitated network visualizations, including co-authorship maps, keyword co-occurrence networks, thematic evolution overlays, and strategic diagrams. These visual tools enabled the interpretation of complex relationships among research actors, themes, and time periods in an accessible manner.

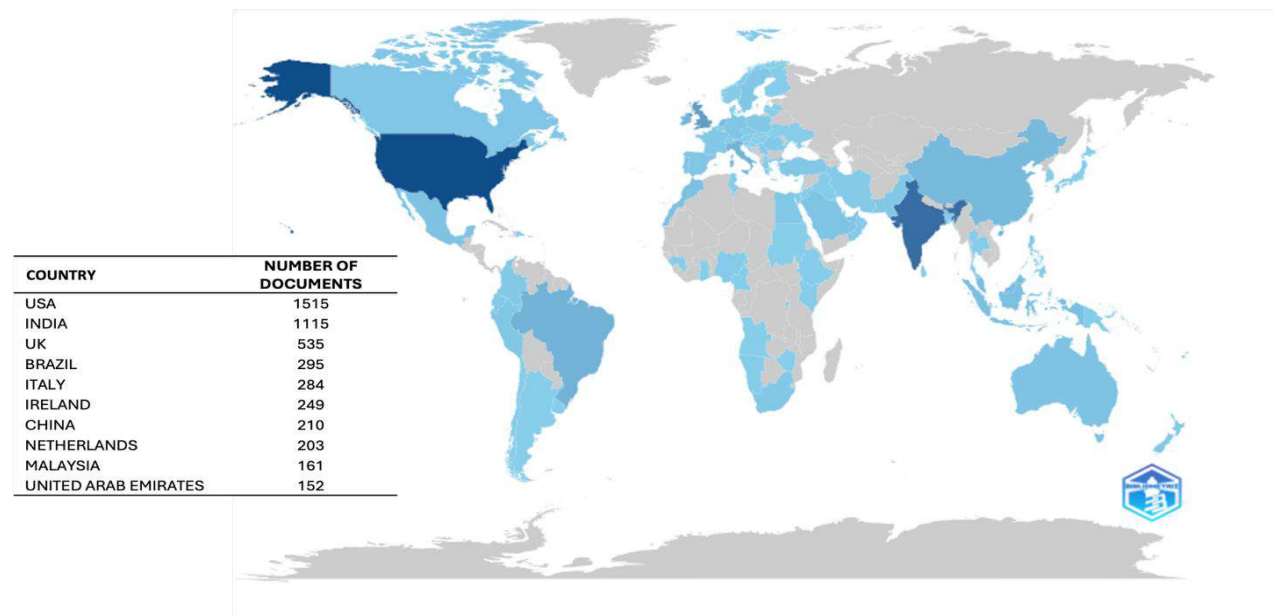**Figure 1.** Methodological framework of the study

The study employed a rigorous four-phase analytical process to map the quality improvement research landscape (Figure 1). First, comprehensive data were retrieved from Scopus, and bibliographic records were systematically collected to ensure a representative dataset. Second, the dataset underwent meticulous pre-processing, where metadata were normalized and standardized to guarantee analytical consistency. Third, performance analysis was conducted to identify field leaders, spotlighting the most influential authors, institutions, countries, and publications shaping quality improvement discourse. Finally, advanced science mapping techniques were applied to visualize the field's intellectual structure, revealing evolving collaboration networks, thematic clusters, and temporal trends. Collectively, these stages told the story of the development of quality research. This multi-stage approach enabled the study to move beyond simple bibliometric counts and to generate meaningful insights into the field's past, present, and future directions.

Results

The global distribution of Lean Six Sigma (LSS) research (Figure 2) demonstrated a landscape that was geographically diverse yet quantitatively imbalanced. The United States (1,515 documents) and India (1,115 documents) dominated scholarly output, reflecting their strong academic infrastructures, industrial demand for process improvement, and long-standing engagement with quality management frameworks. The United Kingdom (535), Brazil (295), Italy (284), and Ireland (249) followed as significant contributors within their regional contexts. Additional notable contributions came from China, the Netherlands, Malaysia, and the United Arab Emirates, underscoring the methodology's expanding relevance across continents.

This distribution mirrored broader economic and developmental patterns. Mature economies leveraged LSS to advance high-value manufacturing, service-sector innovation, and healthcare process optimization, while emerging and developing nations increasingly adopted LSS as a strategic tool for enhancing operational efficiency, global competitiveness, and

sustainable growth. These patterns highlighted both the global appeal of LSS and the unequal capacity for research production, shaped by differences in funding, industrial adoption rates, and policy priorities.

COUNTRY	NUMBER OF DOCUMENTS
USA	1515
INDIA	1115
UK	535
BRAZIL	295
ITALY	284
IRELAND	249
CHINA	210
NETHERLANDS	203
MALAYSIA	161
UNITED ARAB EMIRATES	152

Figure 2. Geographical distribution of respondents across the globe

The bibliometric performance analysis (Table 1) identified Jiju Antony (University of Northumbria, UK) as the most prolific and influential scholar in LSS research, with 147 publications representing 35% of the total output of the top authors garnering more than 6,800 citations and an h-index of 49. He was closely followed by Rajeev Rathi (India) and Jose Arturo Garza-Reyes (UK), each with over 40 publications and high citation averages, particularly in extending LSS into areas such as supply chain sustainability and service-sector quality. Other prominent contributors, including Olivia McDermott (Ireland), Michael Sony (UK), and Ronald Does (Netherlands), advanced LSS applications in healthcare quality, cultural readiness, and statistical rigor. Scholars such as Mahender Singh Kaswan, Vikas Swarankar, Shreeranga Bhat, Elizabeth Cudney, and Mahipal P. Singh enriched the intellectual diversity of the field by contributing valuable regional perspectives from Asia, Europe, and North America. Additionally, Vijaya M. Sunder (India) stood out for his high citation-per-publication ratio (55.05), reflecting significant influence despite a relatively smaller number of publications.

Table I. The list of top 10 authors of lean six sigma research

AUTHOR'S NAME	AFFILIATION	TP (%)	TC	ACP	H-INDEX	RANK
Antony, Jiju	University of Northumbria (United Kingdom)	147 (34%)	6,881	46.8	49	1st
Rathi, Rajeev	National Institute of Technology (India)	41 (9%)	1,714	41.8	22	2nd
Garza- Reyes, Jose Arturo	University of Derby (United Kingdom)	40 (9%)	1,743	43.6	20	3rd
McDermott, Olivia	University of Galway (Ireland)	35 (8%)	578	16.5	12	4th
Sony, Micheal	Oxford Brookes Business School (United Kingdom)	30 (7%)	592	19.7	13	5th
Does, Ronald J.M.M.	Universiteit van Amsterdam (Netherlands)	27 (6%)	1,112	41.9	15	6th
Kaswan, Mahender Singh	Lovely Professional University (India)	22 (5%)	902	41	14	7th
Swarnakar, Vikas	Khalifa University of Science and Technology (United Arab Emirates)	21 (5%)	512	24.4	12	8th
Bhat, Shreeranga	St Joseph Engineering College (India)	20 (5%)	607	30.6	11	9th
Cudney, Elizabeth A.	Missouri University of Science and Technology (United States)	20 (5%)	590	29.5	13	9th
Singh, Mahipal P.	Lovely Professional University (India)	20 (5%)	749	37.5	12	9th
Sunder M, Vijaya M..	Indian School of Business (India)	19 (4%)	1046	55.1	15	10th

*Abbreviations: ACP, average citations per paper: TC, total citations; TP, total publication, Rank was based on TP.

The institutional performance analysis (Table 2) revealed that the University of Northumbria led global LSS research output, contributing 147 publications 35% of the total from the top institutions supported by more than 6,800 citations and an h-index of 49. The Institute of Technology in India and the University of Derby in the United Kingdom followed with 41 and 40 publications, respectively, both maintaining strong citation averages. Other notable contributors included the University of Galway (Ireland) and Oxford Brookes Business School (UK), each advancing LSS applications across diverse sectors. Additional institutions such as the Universiteit van Amsterdam (Netherlands), Lovely Professional University (India), Khalifa University of Science and Technology (UAE), St. Joseph Engineering College (India), and the University of Science and Technology (USA) further demonstrated the geographically distributed nature of LSS research. India's National Institutes of Technology at Kurukshetra and Tiruchirappalli, while producing fewer publications compared to leading institutions, contributed valuable regional insights and domain-specific expertise to the field.

**Table II.** The top 10 institutions of lean six sigma research

AFFILIATION/INSTITUTION	COIUNTRY	TP (%)	TC	ACP	H-INDEX	RANK
Heriot-Watt University	United Kingdom	71 (16%)	3,398	47.9	36	1st
Khalifa University of Science and Technology	United Arab Emirates	49 (11%)	1,004	20.5	21	2nd
University of Galway	Ireland	44 (10%)	774	17.6	16	3rd
Lovely Professional University	India	43 (9%)	1,728	40.2	22	4th
University of Derby	United Kingdom	41 (9%)	1,793	43.7	21	5th
Universiteit van Amsterdam	Netherlands	37 (8%)	892	24.1	17	6th
University of Northumbria	United Kingdom	34 (8%)	482	14.2	11	7th
Universitá degli Studi di Napoli Federico II	Italy	24 (5%)	885	36.9	14	8th

AFFILIATION/INSTITUTION	COUINTRY	TP (%)	TC	ACP	H-INDEX	RANK
University of Strathclyde	United Kingdom	24 (5%)	2,187	91.1	22	8th
Universidade Federal de São Carlos	Brazil	23 (5%)	584	25.4	11	9th
National Institute of Technology Kurukshetra	India	21 (5%)	72	3.4	5	10th
University College Dublin	Ireland	21 (5%)	350	16.7	13	10th
National Institute of Technology Tiruchirappalli	India	21 (5%)	79	3.8	6	10th

*Abbreviations: ACP, average citations per paper: TC, total citations; TP, total publication, Rank was based on TP.

The three-field plot (Figure 3) illustrated the interconnectedness of the LSS research landscape by linking the most cited references (CR) on the left, the key contributing authors (AU) in the center, and the main themes or keywords (KW_Merged) on the right. Foundational works such as Banawi and Abdulaziz's framework for improving construction processes and study on critical failure factors stood out as cornerstones that continued to influence the field. At the center of the network were prolific scholars including Jiju Antony, Rajeev Rathi, Olivia McDermott, Jose Arturo Garza-Reyes, and Michael Sony, whose research shaped both the methodological foundations and practical applications of LSS. On the right, recurring keywords such as *lean six sigma*, *six sigma*, *lean production*, and *process improvement* reflected the field's core priorities, while terms such as *human*, *quality improvement*, and *efficiency* pointed to evolving areas of interest.
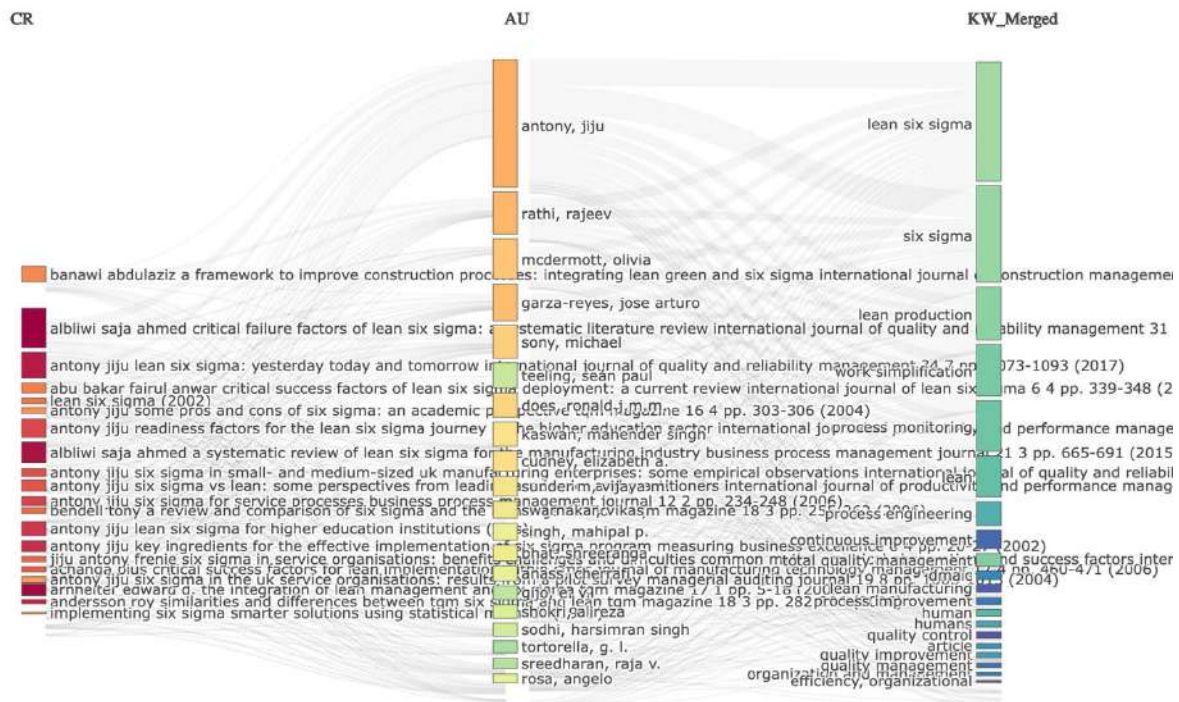
Figure 3. Relationships between cited references, authors, and research keywords

The trend topics analysis (Figure 4) captured the thematic evolution of Lean Six Sigma (LSS) research over the past two decades and revealed a clear trajectory from traditional operational priorities toward more technologically advanced and socially responsive themes. In the mid-2000s, the discourse was dominated by practical efficiency drivers such as *inventory control* and *industrial management*, reflecting LSS's strong manufacturing roots and its early role in streamlining production processes. Over time, the thematic focus progressively expanded to incorporate forward-looking priorities such as *sustainability*, *Industry 4.0*, *machine learning*, and *quality of service*, signaling the integration of LSS with digital transformation and broader organizational performance goals. Particularly notable was the recent surge in terms such as *human*, *health services*, and *sustainable development*, which pointed to an increasing recognition of the human-centric and societal dimensions of process improvement. This thematic shift illustrated how LSS evolved beyond a narrow industrial efficiency framework into a versatile, cross-sector approach that addressed technological advancement, environmental responsibility, and public service quality, aligning closely with contemporary global priorities.
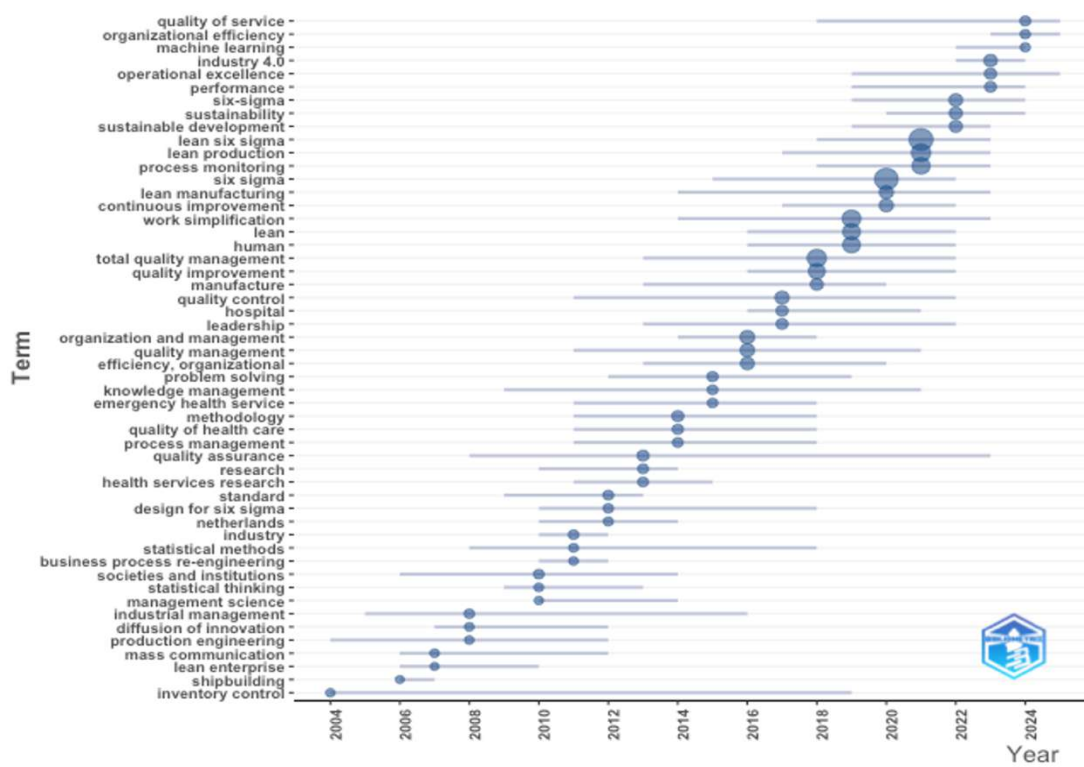
Figure 4. Temporal trends and frequency of research terms in the field

The co-occurrence network (Figure 5a) unveiled two primary thematic clusters in LSS research and demonstrated a meaningful convergence of industrial and service-oriented domains. The red cluster, dominated by *Six Sigma*, reflected a stronger emphasis on manufacturing-related concepts such as *Industry 4.0*, *sustainable development*, *manufacture*, *efficiency*, and *big data*. This aligned with modern trends that integrated LSS with digital transformation, particularly under Industry 4.0 paradigms. Meanwhile, the green cluster, centered on *Total Quality Management*, placed greater emphasis on organization and management, healthcare delivery, workflow, and public health. This shift toward healthcare applications and process workflows illustrated LSS's extension into service-sector improvement an evolution corroborated by recent bibliometric findings of increasing LSS adoption in healthcare contexts.

The overlay visualization (Figure 5b) revealed the temporal evolution of LSS research and demonstrated a gradual thematic transition from traditional quality management toward more contemporary, interdisciplinary applications. Early research (depicted in blue) concentrated on foundational concepts such as *organization and management*, *standardization*, and *total quality management*. Over time, the focus shifted toward integration with advanced manufacturing, sustainability, and healthcare systems, with mid-phase studies (green) emphasizing *Industry 4.0*, *efficiency*, *process control*, and *healthcare delivery*. The most recent research fronts (yellow) highlighted emergent topics such as *machine learning*, *big data analytics*, *COVID-19 response*, and *sustainable development*, reflecting LSS's adaptability to digital transformation and global crises (Nadeem *et al*., 2023; Kurnia and Purba, 2021). This trajectory underscored the methodology's evolving role in enhancing both operational performance and societal resilience.

Figure 5. (a) Keywork co-occurrence network with cluster analysis **(b)** Overlay visualization of keyword co-occurrence by average publication year

The integrated analysis of the global and author collaboration networks highlighted the deeply interconnected and increasingly internationalized nature of Lean Six Sigma (LSS)

research. The global map (Figure 6a) revealed a dense web of cross-border partnerships, with particularly strong research linkages among the United States, India, and the United Kingdom three countries that acted as pivotal hubs within the global LSS knowledge network. These collaborations extended well beyond these core players, encompassing academic and institutional ties across Europe, Asia, Africa, and the Americas. This widespread network facilitated a rich exchange of methodologies, sectoral applications, and cultural perspectives. Such international collaboration not only enhanced the adaptability of LSS frameworks but also accelerated their integration into diverse industrial and service contexts worldwide.

Complementing this, the author collaboration network (Figure 6b) identified Jiju Antony as the central scholarly node, exhibiting the highest degree of connectivity and influence within the field. His position at the nexus of multiple research communities underscored his critical role in shaping both the theoretical foundations and practical applications of LSS. Surrounding Antony were other key contributors, including Rajeev Rathi, Mahender Singh Kaswan, Olivia McDermott, and Michael Sony, each of whom brought specialized expertise and regional insights that enriched the collective research agenda. Together, these scholars formed an interconnected leadership core that drove thematic innovation, fostered global research cohesion, and ensured that LSS continued to evolve in response to emerging technological, operational, and societal challenges.
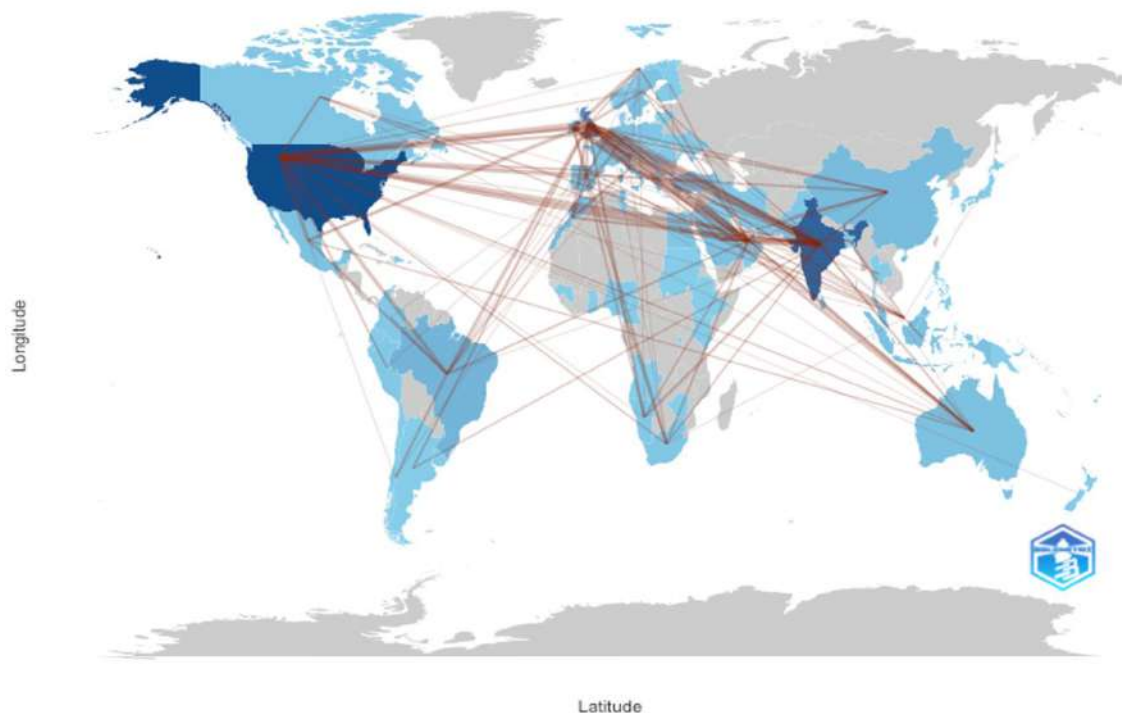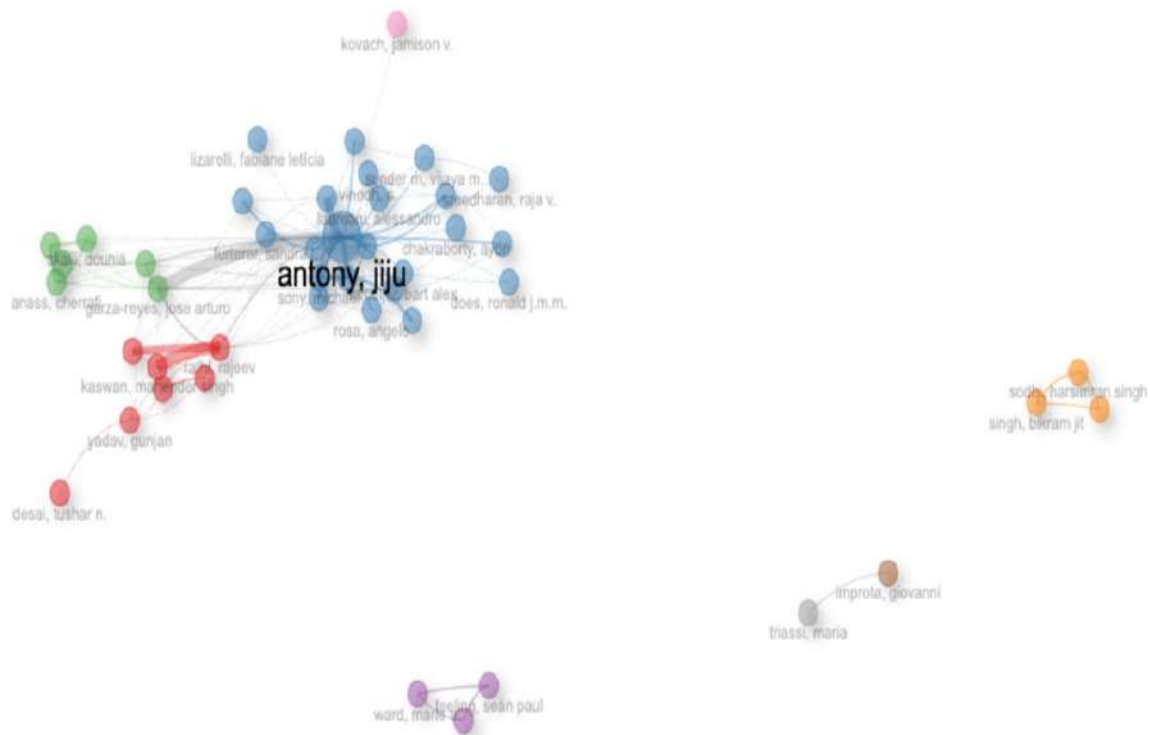
Figure 6. (a) International collaboration network in the research field **(b)** Co-authorship network of leading researchers

The thematic map (Figure 7) positioned *total quality management* and *human/humans* within the niche quadrant, signaling areas that were deeply developed but exhibited limited integration into the broader Lean Six Sigma (LSS) discourse. In contrast, *lean six sigma*, *six sigma*, and *lean production* occupied the basic themes quadrant, underscoring their strong foundational role with broad connectivity across the field. Quantitatively, *lean six sigma* dominated with a cluster frequency of 9,149, reinforcing its prominence, while *total quality management* followed with 4,591 occurrences, reflecting its enduring conceptual density.
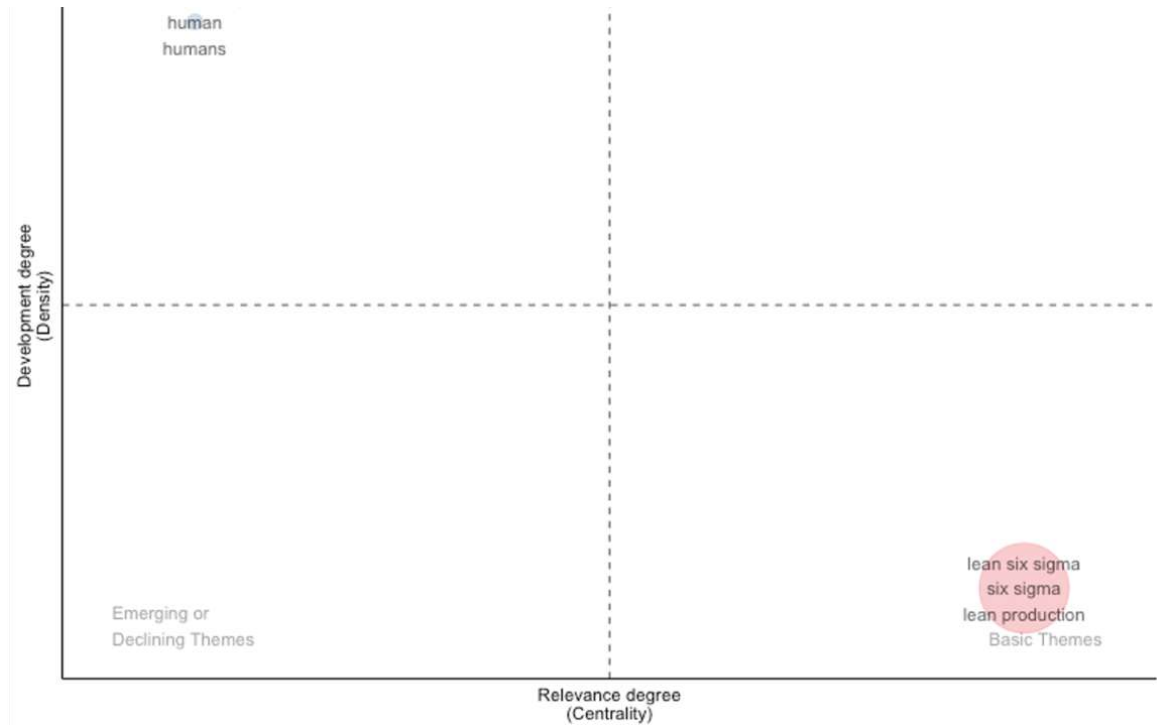
Figure 7. Strategic diagram of thematic clusters

The hierarchical clustering analysis (Figure 8) revealed a clear thematic structure within LSS and related quality management research, grouping concepts into interconnected clusters that reflected both methodological foundations and sector-specific applications. Core methodological terms such as *lean six sigma*, *six sigma*, *lean production*, and *total quality management* formed a tightly knit group, underscoring their shared role as foundational frameworks in process improvement. Adjacent clusters incorporated *process monitoring*, *work simplification*, and *continuous improvement*, which highlighted operational optimization strategies central to LSS practice. Another distinct grouping emphasized application contexts such as *healthcare quality*, *patient care*, and *customer satisfaction*, reflecting the field's strong orientation toward service quality and outcome enhancement. Emerging technological and strategic drivers including *Industry 4.0* and *operational excellence* appeared in integrative clusters, indicating ongoing convergence between digital transformation initiatives and continuous improvement philosophies.
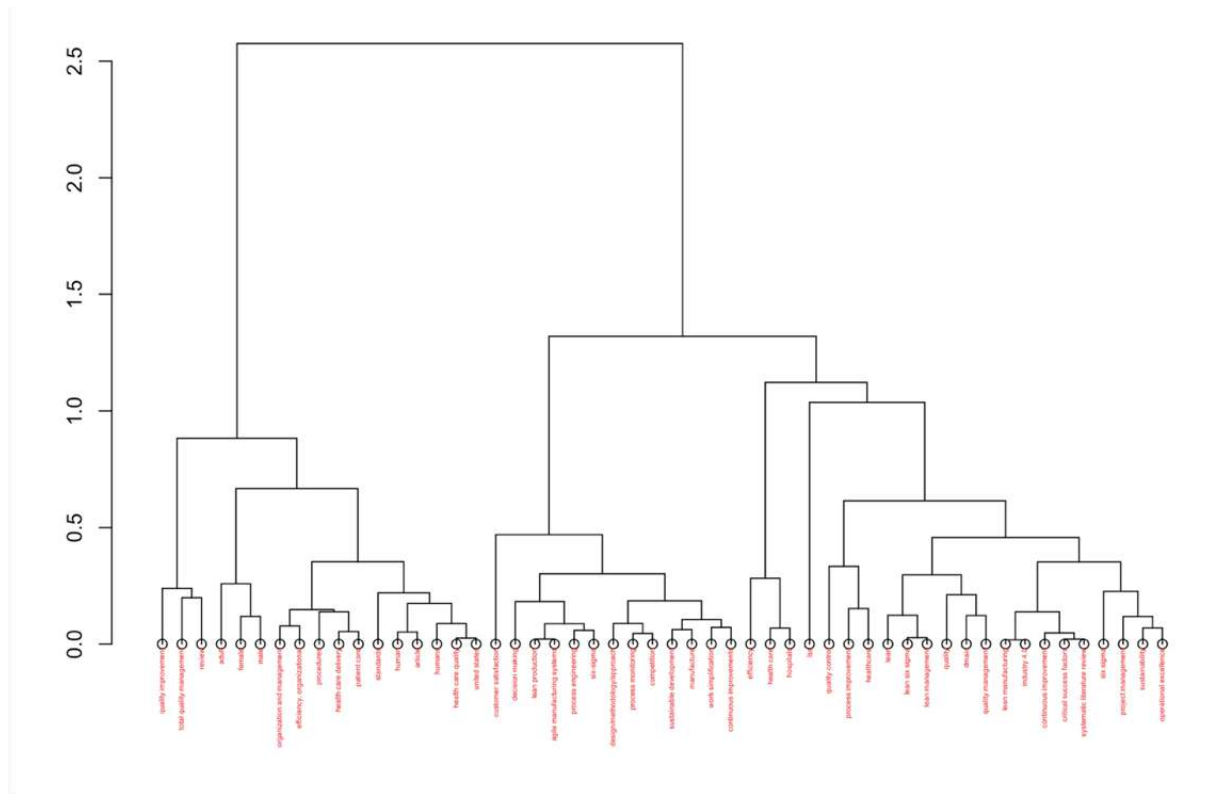
Figure 8. Hierarchical clustering dendrogram of keywords

Discussions

From the perspective of the United Nations Sustainable Development Goals (SDGs), LSS research demonstrated strong alignment with global priorities. Leading contributors such as the United States, India, and the United Kingdom leveraged robust infrastructures and industry academia linkages to advance operational excellence. Mature economies drove innovation and advanced manufacturing, while emerging economies employed LSS to build capacity and global competitiveness (Antony, 2020; Sony *et al*., 2020). These dynamics supported SDG 9 (*Industry, Innovation, and Infrastructure*) by enhancing productivity, SDG 12 (*Responsible Consumption and Production*) through waste reduction, and SDG 3 (*Good Health and Well-being*) via improvements in patient safety and hospital efficiency (McDermott *et al*., 2022). The global network of collaborations also reflected SDG 17 (*Partnerships for the Goals*), underscoring the role of cross-border cooperation in knowledge diffusion. This finding aligned with evidence that international co-authorship improved research quality and visibility, with cross-country collaborations producing more impactful articles (Thelwall *et al*., 2022).

Thematic analyses revealed two dominant yet interconnected clusters: one emphasizing manufacturing, Industry 4.0, and sustainability, and another focused on healthcare, service quality, and organizational management (Macias-Aguayo *et al*., 2022; Hasan *et al*., 2023). Research on the integration of LSS with Industry 4.0 highlighted both barriers and enablers shaping its adoption (Macias-Aguayo *et al*., 2022). Earlier research emphasized industrial management and quality assurance, whereas more recent studies highlighted agile

methodologies, big data analytics, and patient-centered healthcare. Healthcare emerged as a particularly critical domain, where LSS reduced errors and costs while improving outcomes, thereby demonstrating societal as well as industrial value. In the industrial domain, case-based studies reinforced the value of structured frameworks. For instance, a DMAIC-based LSS framework significantly improved efficiency and product quality in the Indian automotive industry, underscoring the role of context-specific approaches in sustaining operational gains (Teli *et al*., 2021).

Emerging priorities such as machine learning, pandemic resilience, and sustainable operations positioned LSS as more than a process-improvement tool. It served as a strategic enabler of innovation, societal resilience, and sustainable development (Nadeem et al., 2023; Kurnia and Purba, 2021). These shifts also highlighted opportunities for cross-integration of Lean and Industry 4.0 practices (Alsadi *et al*., 2023). By integrating methodological foundations with sector-specific applications, LSS continued to evolve as a globally relevant framework for addressing both industrial challenges and societal needs.

Conclusion

Guided by its objective to map the intellectual structure, key contributors, and thematic evolution of Lean Six Sigma (LSS), this bibliometric analysis confirmed that LSS had developed into a globally significant framework bridging industrial efficiency with service quality, healthcare innovation, and sustainability focused practices. The results demonstrated how leading scholars, diverse institutions, and strong international collaborations shaped the field, enabling the transfer of knowledge across regions and sectors. Over time, LSS research progressed from foundational process improvement to the integration of advanced technologies, data analytics, and human centered approaches that addressed complex societal and industrial needs. This thematic convergence directly supported several United Nations Sustainable Development Goals, most notably SDG 9, SDG 12, and SDG 3, by promoting innovation, resource efficiency, and improved health outcomes. By delivering a comprehensive overview of the field's trajectory and emerging priorities, this study provided a strategic foundation for future research aimed at leveraging LSS as a catalyst for both operational excellence and sustainable development in an interconnected global economy.

The dominance of the United Kingdom, India, and the United States reflected a fusion of mature innovation systems and rapid capability development, while the scholarly output of top authors accelerated the refinement and global dissemination of best practices. The rising prominence of healthcare applications highlighted LSS's adaptability to high impact sectors, where operational efficiency translated into both economic savings and lives saved. Similarly, the emphasis on certifications signaled a strategic move toward global standardization, ensuring that LSS principles remained relevant and transferable across industries and borders. Collectively, these elements positioned LSS not merely as a process improvement methodology but as a globally adaptable framework capable of driving sustainable industrial growth, enhancing service quality, and fostering international collaboration, aligning closely with the imperatives of a dynamic, interconnected world economy.

Article Information and Declarations

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