

Mapping the Evolution of Six Sigma in Quality Management: A Bibliometric Review (2000–2025)

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Article Info

Article history:

Received Sep, 2025

Revised Sep, 2025

Accepted Sep, 2025

Keywords:

Bibliometric Analysis;

Lean Six Sigma;

Quality Management;

Six Sigma;

Total Quality Management

ABSTRACT

This study conducts a bibliometric review to map the evolution of Six Sigma in the field of quality management from 2000 to 2025. Using the Scopus database as the primary source and analyzed through VOSviewer, the study explores publication trends, keyword co-occurrence, and collaboration networks to uncover the intellectual structure and thematic progression of Six Sigma research. The findings highlight the central role of Six Sigma and Total Quality Management (TQM) as dominant research themes, while emerging areas such as Lean Six Sigma, healthcare quality, process improvement, and risk management illustrate the method's expansion into diverse industries and organizational functions. The density and overlay visualizations further reveal a shift from traditional manufacturing-based applications toward service sectors, healthcare systems, and strategic management contexts, demonstrating the adaptability and resilience of Six Sigma in addressing contemporary challenges. This review contributes to the literature by offering both a theoretical mapping of research trajectories and practical implications for organizations aiming to leverage Six Sigma for sustainable quality improvement and innovation.

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1. INTRODUCTION

The pursuit of quality improvement has been one of the most enduring priorities in organizational management, particularly since the advent of the modern industrial era. Companies across sectors, from manufacturing to services, have consistently sought structured methodologies to minimize variation, eliminate defects, and enhance customer satisfaction. Among these methodologies, Six Sigma has emerged as one of the most influential and widely adopted quality management approaches in the last

three decades [1], [2]. Developed at Motorola in the mid-1980s and popularized by General Electric during the 1990s, Six Sigma combines statistical tools, process improvement strategies, and organizational change management to achieve performance excellence. Its appeal lies in its structured problem-solving framework, most notably the DMAIC (Define, Measure, Analyze, Improve, Control) cycle, which provides practitioners with a systematic roadmap for quality enhancement and process optimization. Over time, Six Sigma has transcended its origins in manufacturing, expanding into services,

healthcare, finance, supply chain management, and even higher education [3], [4].

The growing body of literature reflects this expansion, with thousands of academic articles, case studies, and reviews published since 2000. These studies explore not only the technical applications of Six Sigma but also its integration with other quality management paradigms such as Total Quality Management (TQM), Lean Manufacturing, and ISO-based systems. Scholars have debated its merits and limitations, examined its impact on organizational performance, and investigated the human and cultural factors influencing its adoption. With globalization and digitalization reshaping industries, Six Sigma has also evolved by incorporating new tools from big data analytics, Industry 4.0, and artificial intelligence. As a result, Six Sigma is no longer a static methodology but rather a dynamic field of study that reflects broader shifts in managerial priorities, technological advances, and societal expectations of quality [5], [6].

Despite its enduring relevance, the academic landscape of Six Sigma research remains highly fragmented. Various disciplines (operations management, engineering, healthcare management, and business administration) have contributed to the discourse, each emphasizing different facets of the methodology. Some streams focus heavily on statistical rigor, while others highlight organizational culture, leadership, or human resource dimensions. Furthermore, new hybrid concepts such as Lean Six Sigma (LSS) have gained prominence, blending waste reduction from Lean with defect minimization from Six Sigma. This diversity of perspectives makes it increasingly difficult to obtain a holistic understanding of how Six Sigma research has evolved over time and where it might be heading. Bibliometric analysis offers a systematic solution to this challenge by mapping research trends, influential works, key authors, and thematic clusters across a given period [7]–[9].

The years 2000 to 2025 represent a particularly important timeframe for

examining Six Sigma's trajectory. At the beginning of the century, organizations were grappling with globalization, supply chain integration, and heightened customer expectations. Six Sigma was championed as a way to remain competitive by achieving operational excellence. As the 2010s unfolded, Lean Six Sigma became mainstream, reflecting the trend toward integration of improvement methodologies. More recently, the post-2020 period has been marked by digital transformation, sustainability imperatives, and the disruptive impact of the COVID-19 pandemic on global supply chains and service systems. Each of these contextual shifts has influenced the ways Six Sigma is theorized, implemented, and studied. A bibliometric review spanning 25 years can thus capture the rise, transformation, and current positioning of Six Sigma in academic and professional discourse.

In addition to capturing historical trends, a bibliometric approach can also highlight gaps in knowledge and opportunities for future exploration [10]. For instance, while Six Sigma has demonstrated success in large corporations, questions remain about its adaptability to small and medium-sized enterprises (SMEs), startups, and digital-first organizations. Similarly, while the methodology is often praised for its structured rigor, critics argue that it can be rigid, overly statistical, or resource-intensive. Moreover, as industries increasingly prioritize sustainability, resilience, and agility, there is a need to understand how Six Sigma integrates with these emerging paradigms. By systematically mapping the literature, researchers can provide a clearer picture of how the methodology has adapted to new demands and where scholarly attention should be directed in the coming years.

Although Six Sigma has been extensively studied, the field lacks a comprehensive and updated bibliometric review that synthesizes its scholarly evolution across the past quarter century. Prior reviews have often been limited in scope, focusing on specific industries, regions, or timeframes, leaving unanswered questions about the broader development of the field. As a result,

it remains unclear which themes have dominated Six Sigma research, which authors and institutions have shaped its trajectory, and how its focus has shifted in response to technological, economic, and social changes. Without such a systematic overview, scholars and practitioners risk working with an incomplete or outdated understanding of Six Sigma's position in contemporary quality management discourse. The objective of this study is to conduct a bibliometric review of Six Sigma research published between 2000 and 2025, with the aim of mapping its intellectual structure, thematic evolution, and emerging trends within the field of quality management.

2. RESEARCH METHODS

To comprehensively chart the evolution of Six Sigma within the domain of quality management from 2000 to 2025, this bibliometric assessment adopts a multi-stage methodology encompassing data collection, data preprocessing and analysis, and visualization and interpretation. First, we retrieved relevant publications from the and Scopus. The search strategy included keywords such as "Six Sigma," "Lean Six Sigma," and "quality management," combined using Boolean operators (e.g., "Six Sigma" AND "quality management") to ensure high relevance. Only literature published in peer-reviewed sources (including journals, conference proceedings, and reviews) between January 1, 2000, and August 31, 2025, was considered. We deliberately excluded non-academic publications, non-English works, and duplicates to maintain consistency and ensure reliability. Complete bibliographic metadata were extracted for each record, comprising titles, authors, publication years, source

outlets, abstracts, keywords, citations, and institutional affiliations.

Following data collection, preprocessing was conducted to improve accuracy and consistency. Duplicate entries were removed, particularly in cases where the same articles were indexed in both databases. Author names, institutional affiliations, and keywords were standardized to reduce ambiguity caused by variations (e.g., "Lean Six Sigma" vs. "LSS"). The cleaned dataset was then imported into VOSviewer, which specializes in constructing and visualizing bibliometric networks [11]. Key bibliometric indicators were calculated, including annual publication outputs, citation counts, and journal-level contributions. The analysis focused on three main dimensions: co-authorship networks to explore collaboration patterns, co-citation networks to identify influential studies and intellectual structures, and keyword co-occurrence networks to detect thematic clusters and research trends.

The results were visualized and interpreted through VOSviewer's mapping and clustering capabilities. The software generated network maps where nodes represented items such as authors, documents, or keywords, and links reflected relationships such as co-authorship, citation, or co-occurrence. Clusters of related nodes were detected using VOSviewer's clustering algorithm, allowing for the identification of dominant research themes and their interconnections. Temporal overlays were applied to track thematic evolution, illustrating how Six Sigma scholarship shifted focus across decades, for instance, from manufacturing-centered applications in the early 2000s to Lean Six Sigma integration in the 2010s and sustainability or digital transformation in the 2020s.

3. RESULTS AND DISCUSSION

3.1 Co-Authorship Analysis

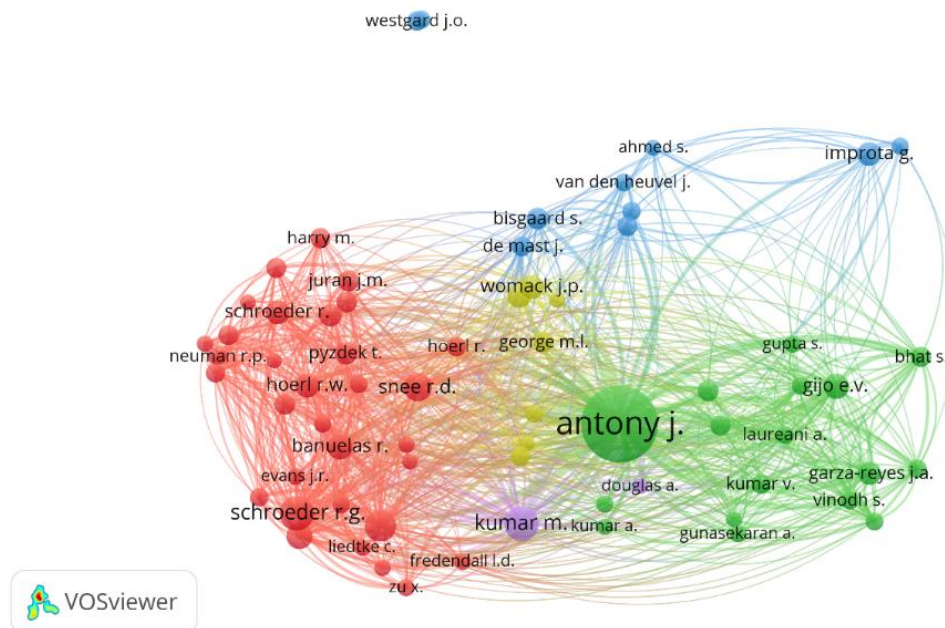


Figure 1. Author Visualization

Source: Data Analysis

Figure 1 illustrates the intellectual structure and collaboration patterns within Six Sigma research between 2000 and 2025. The size of each node reflects the number of publications or influence of a given author, while the colors represent distinct clusters of closely connected scholars. The largest and most central node, Antony J., emerges as the dominant contributor, acting as a central hub that connects multiple clusters, indicating his pivotal role in advancing Six Sigma literature. The green cluster, surrounding Antony J., includes prominent authors such as Laureani A., Vinodh S., and

Garza-Reyes J.A., highlighting a strong collaborative community focused on contemporary applications of Six Sigma in manufacturing and service sectors. The red cluster, featuring figures like Juran J.M., Schroeder R.G., and Pyzdek T., represents foundational contributors whose works are strongly interconnected and emphasize the classical statistical and managerial roots of Six Sigma. Meanwhile, the blue cluster, with authors such as Improta G. and Ahmed S., indicates a research stream applying Six Sigma in healthcare and public service contexts.

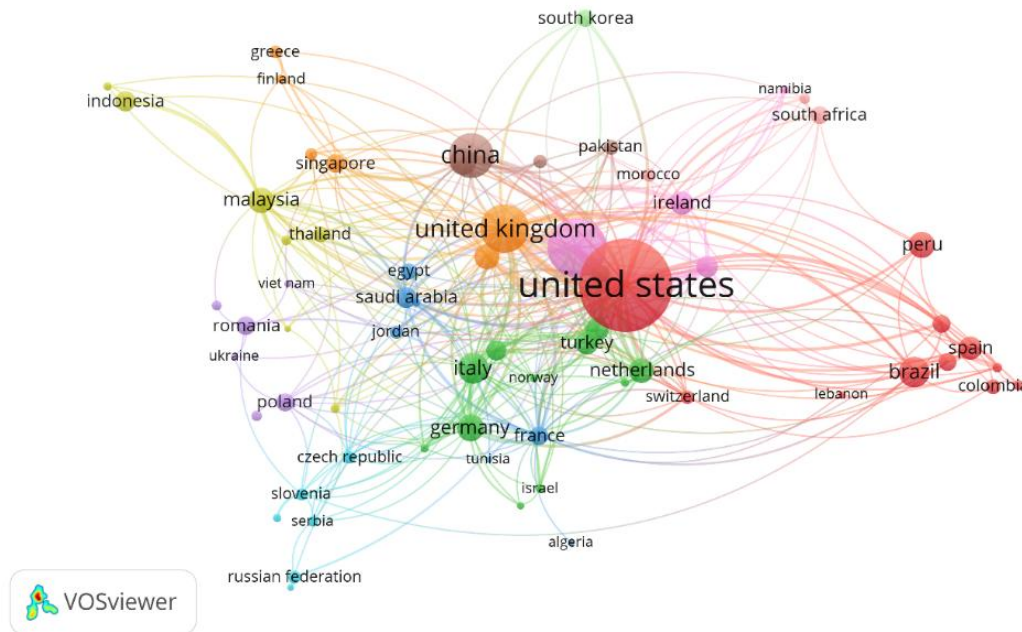


Figure 2. Country Visualization
Source: Data Analysis

Figure 2 highlights the global distribution and interconnectedness of Six Sigma research between 2000 and 2025. The United States stands out as the most dominant and central contributor, with extensive collaborative ties to nearly all other regions, underscoring its role as the intellectual and institutional hub of Six Sigma scholarship. The United Kingdom, China, Italy, Germany, and the Netherlands also appear as significant nodes, forming strong transnational networks that facilitate cross-pollination of ideas. Countries in Latin America,

particularly Brazil, Spain, and Peru, form a distinct cluster, reflecting the regional adoption and contextualization of Six Sigma practices. Similarly, Asian countries such as Malaysia, Singapore, and India are tightly connected with both Western and regional partners, highlighting their growing role in quality management research. The presence of emerging economies like Indonesia, Egypt, and South Africa, though smaller in scale, suggests the increasing diffusion of Six Sigma into diverse industrial and service contexts.

3.2 Citation

Table 1. Most Cited Article

Citations	Author and Year	Title
670	[12]	<i>Six Sigma: A goal-theoretic perspective</i>
635	[13]	<i>Six Sigma: Definition and underlying theory</i>
514	[14]	<i>Lean production, six sigma quality, TQM and company culture</i>
474	[15]	<i>An overview of continuous improvement: From the past to the present</i>
474	[16]	<i>Critical success factors for the successful implementation of six sigma projects in organisations</i>
470	[17]	<i>The integration of lean management and Six Sigma</i>
441	[18]	<i>Critical failure factors of lean Six Sigma: A systematic literature review</i>
428	[1]	<i>The evolving theory of quality management: The role of Six Sigma</i>
423	[19]	<i>Lean in healthcare: A comprehensive review</i>
393	[20]	<i>Similarities and differences between TQM, six sigma and lean</i>

Source: Scopus, 2025

3.3 Co-Occurrence Network of Keyword

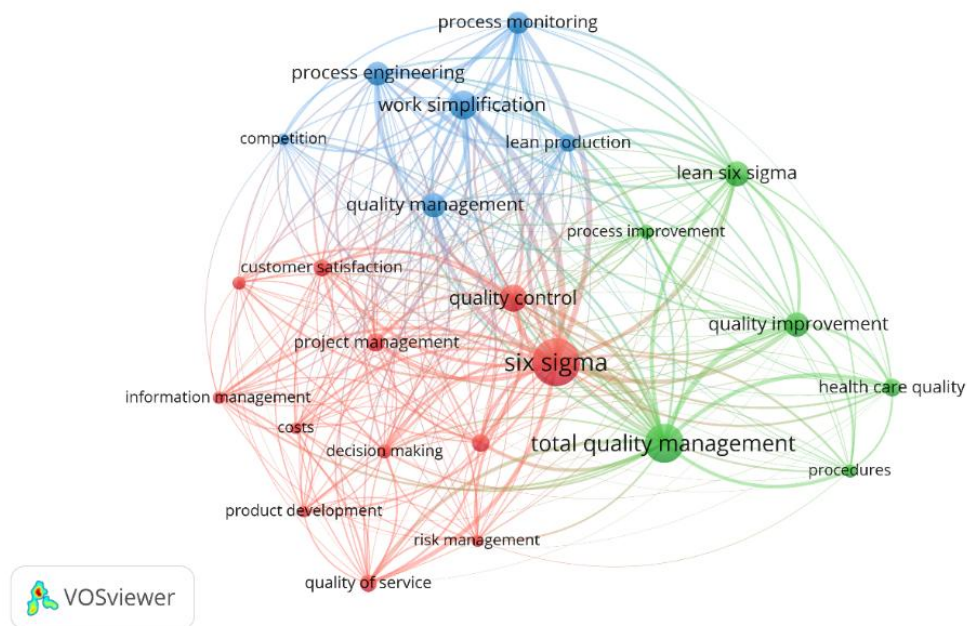


Figure 3. Network Visualization
Source: Data Analysis

Figure 3 above provides a comprehensive view of the conceptual landscape of Six Sigma research in quality management between 2000 and 2025. At the center of the map, the term “Six Sigma” emerges as the most prominent node, indicating its foundational role as the core concept around which related topics and methodologies are clustered. Closely connected terms such as “quality control,” “total quality management,” and “lean Six Sigma” demonstrate the intertwined nature of improvement frameworks, suggesting that scholars consistently study Six Sigma not as an isolated methodology but as part of a broader ecosystem of quality management practices. The dense connections also reveal the interdisciplinary nature of the field, linking technical process improvement with managerial and strategic considerations.

The red cluster predominantly emphasizes managerial and organizational dimensions, including keywords such as “customer satisfaction,” “project management,” “decision making,” and “quality of

service.” This indicates that a substantial portion of the literature views Six Sigma through the lens of organizational performance and customer-oriented outcomes. Studies in this cluster are particularly concerned with how Six Sigma contributes to strategic objectives, enhances service quality, and drives customer value. The strong interconnections among project management, cost control, and risk management highlight the practical implementation challenges and organizational alignment necessary for Six Sigma to succeed, reflecting its role as both a technical and managerial framework.

The green cluster illustrates the integration of Six Sigma with other quality methodologies, most notably Total Quality Management (TQM), Lean Six Sigma, and process improvement approaches. The presence of terms such as “healthcare quality” and “procedures” suggests the diversification of Six Sigma applications beyond manufacturing, particularly in healthcare and service industries. This cluster demonstrates how Six Sigma has evolved into a hybrid

model, combining elements from TQM and Lean to form a more adaptable and holistic system. The prominence of healthcare-related terms further underscores the methodology’s increasing relevance in patient safety, process efficiency, and service delivery, a trend that gained momentum in the 2010s and accelerated after the COVID-19 pandemic.

The blue cluster focuses on the technical and operational aspects of Six Sigma, with keywords such as “process monitoring,” “process engineering,” “work simplification,” and “lean production.” This indicates the persistence of research streams grounded in statistical rigor, process optimization,

and engineering principles—the original backbone of Six Sigma. The coexistence of technical and managerial clusters highlights a dual trajectory in the field: while early research emphasized defect reduction and statistical control in manufacturing processes, later studies increasingly broadened the scope to include strategic, customer-driven, and cross-sectoral applications. Together, the clusters reflect Six Sigma’s transformation from a narrowly defined process-improvement methodology into a multifaceted framework that spans technical, managerial, and service-oriented dimensions of quality management.

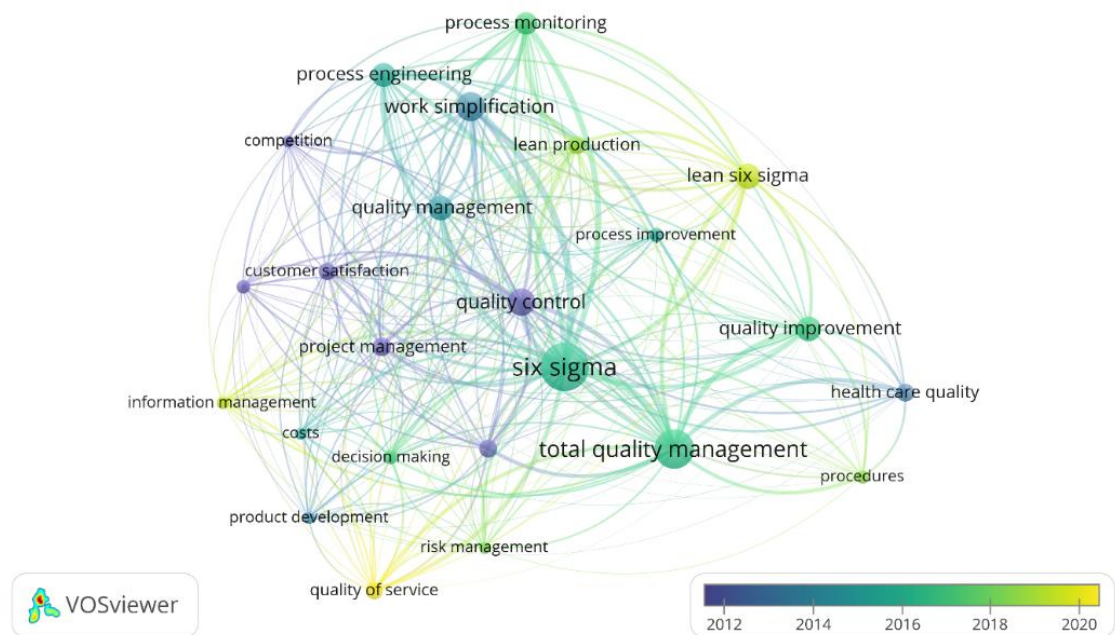


Figure 4. Overlay Visualization
Source: Data Analysis

Figure 4 shows the chronological evolution of thematic priorities in the field. Early studies, indicated by darker blue and purple tones (2012–2014), concentrated on the traditional foundations of Six Sigma such as “quality control,” “customer satisfaction,” and “project management.” These themes reflect the initial emphasis on applying statistical methods and structured improvement frameworks to reduce

defects, enhance consistency, and align outcomes with customer expectations. During this period, Six Sigma was still largely framed within its original manufacturing context, emphasizing rigor in monitoring and controlling processes. From 2015 to 2017, represented by green tones, the research focus began to expand toward integration with other quality management methodologies, most notably Total Quality Management

(TQM), Lean Production, and Process Improvement. This shift highlights the rise of Lean Six Sigma, which combines waste elimination from Lean with variation reduction from Six Sigma, broadening the applicability of the methodology to both manufacturing and service industries. At the same time, themes such as risk management and decision making emerged more prominently, reflecting organizations' growing interest in aligning operational excellence with strategic business priorities. The integration of Six Sigma with broader management concerns signals a movement away from purely technical approaches toward more holistic frameworks.

More recent studies, indicated by yellow tones (2018–2020), emphasize service quality, healthcare quality, and product development, suggesting the diversification of Six Sigma applications into new sectors. The increasing prominence of terms like “healthcare quality” illustrates the methodology's adaptation to patient safety, clinical processes, and hospital management—areas that became particularly relevant with the rising demand for efficiency and resilience in healthcare systems. Likewise, the focus on service quality demonstrates the shift toward customer-centered industries, while product development indicates Six Sigma's alignment with innovation and market competitiveness.

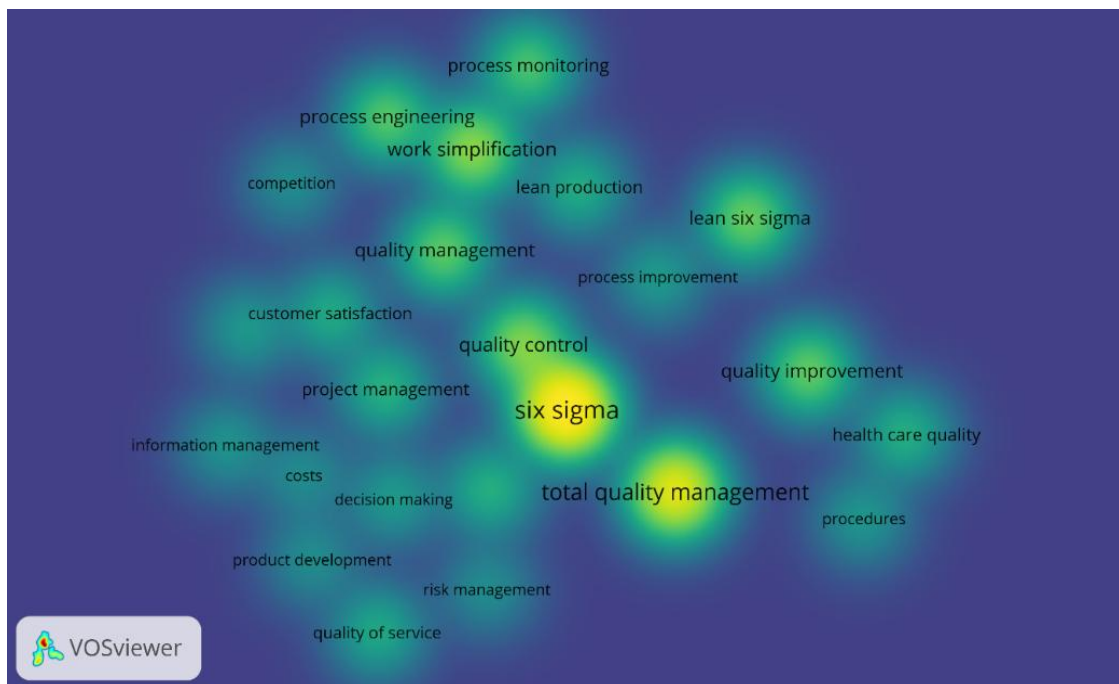


Figure 5. Density Visualization
Source: Data Analysis

Figure 5 illustrates the concentration and interconnectedness of dominant themes within quality management studies from 2000 to 2025. At the core, the terms “six sigma” and “total quality management” appear with the highest density, reflecting their central role in the literature. Closely surrounding these are related concepts such as “quality control,” “process improvement,” and “quality improvement,” which highlight

the methodological and practical focus of Six Sigma on enhancing operational efficiency and reducing variability. The presence of “customer satisfaction” and “project management” in the cluster further emphasizes the managerial and client-oriented aspects of Six Sigma, suggesting its broad integration into organizational strategy beyond technical applications. Additionally, the visualization shows the evolution and

diversification of Six Sigma applications into complementary fields and industries. Keywords such as “lean production,” “lean six sigma,” and “work simplification” indicate the strong linkage with Lean methodologies, reinforcing the trend of hybrid approaches aimed at maximizing efficiency while minimizing waste. The emergence of “health care quality,” “quality of service,” and “product development” underscores the expansion of Six Sigma from manufacturing into healthcare, service industries, and innovation-driven sectors. Other terms like “risk management,” “decision making,” and “information management” reflect the growing recognition of Six Sigma as a decision-support and risk-mitigation framework.

3.4 Practical Implications

The findings of this study offer several important insights for practitioners. First, the visualization highlights Six Sigma and Total Quality Management (TQM) as central themes, showing that these methodologies remain highly relevant for organizations seeking to enhance operational efficiency and customer satisfaction. Managers can leverage this knowledge to align improvement initiatives with proven frameworks and integrate complementary practices such as Lean Six Sigma, process improvement, and risk management into their strategies. Second, the study reveals the growing application of Six Sigma beyond manufacturing, particularly in healthcare, service industries, and product development, indicating that practitioners in non-traditional sectors can adopt these methodologies to achieve measurable performance improvements. The clustering of keywords such as decision-making, information management, and project management suggests that Six Sigma is evolving as a strategic tool for organizational transformation, encouraging practitioners to view it not merely as a statistical tool but as part of an integrated management system.

3.5 Theoretical Contributions

From a theoretical standpoint, this study contributes to the intellectual structure of Six Sigma research by systematically mapping the evolution and interconnection of key concepts. The use of bibliometric analysis with VOSviewer provides an empirical foundation to identify core themes (Six Sigma, TQM, quality control) and their emerging linkages with other domains, such as lean production, service quality, and healthcare quality management. This contributes to theory building by expanding the understanding of Six Sigma as a multi-disciplinary paradigm that spans operations management, strategic management, and service innovation. Moreover, by demonstrating the co-occurrence and density of keywords, the study highlights the integration of Six Sigma with decision science and risk management theories, suggesting that future research should further explore these intersections. In essence, the research adds value by contextualizing Six Sigma not just as a quality improvement tool, but as a theoretical construct embedded in broader organizational and strategic frameworks.

3.6 Limitations

Despite its contributions, this study has certain limitations. First, the bibliometric analysis relies solely on Scopus as the primary database, which, while comprehensive, may exclude relevant publications indexed in other sources such as Web of Science, IEEE, or Google Scholar. This could lead to a partial representation of the research landscape. Second, the analysis is limited to keyword co-occurrence and density mapping, meaning it does not capture the full depth of theoretical or methodological nuances in individual studies. Third, while VOSviewer provides robust visualization, it is inherently quantitative and descriptive, thus not addressing the qualitative dimensions such as the contextual application of Six

Sigma in different industries. Finally, the study adopts a time-bound perspective (2000–2025), which may not reflect the very latest emerging works or trends beyond the dataset cutoff. Future research could overcome these limitations by employing multi-database approaches, mixed-method bibliometric-content analysis, and longitudinal comparative studies to provide a richer and more comprehensive picture.

4. CONCLUSION

This bibliometric review mapped the evolution of Six Sigma research in the context of quality management from 2000 to 2025, offering a comprehensive view of its intellectual structure, thematic development, and global collaboration patterns. The

findings reveal that Six Sigma and Total Quality Management (TQM) remain the central pillars of quality improvement research, while emerging themes such as Lean Six Sigma, process improvement, healthcare quality, and risk management reflect the method's adaptation to contemporary organizational needs. The keyword and density visualizations highlight not only the enduring relevance of Six Sigma in manufacturing but also its growing application in service and healthcare sectors, signaling a broadening scope of impact. Moreover, the global collaboration networks underscore the role of leading countries such as the United States, United Kingdom, China, and Italy in advancing the discourse, while also pointing to increasing contributions from emerging economies.

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