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iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 19 No. 22 (2025) | OPEN ACCESS

https://doi.org/10.3991/ijim.v19i22.58227

PAPER

Mobile Technologies in Predictive Maintenance for Industry 4.0: A Bibliometric Analysis of Research Trends, Knowledge Structure, and Future Directions

Samrena Jabeen[1], Huma Sikandar[2](✉), Muhammad Muddassar Khan[2], Khadija Sikandar[3]

[1]Arab Open University, A'ali, Bahrain

[2]Abbottabad University of Science and Technology, Havelian, Pakistan

[3]National University of Sciences & Technology, Islamabad, Pakistan

huma.sikandar@gmail.com

ABSTRACT

The convergence of mobile technologies with predictive maintenance (PdM) systems represents a transformative paradigm in Industry 4.0 manufacturing environments, enabling real-time fault detection, remote diagnostics, and intelligent maintenance scheduling. This study presents a comprehensive bibliometric analysis mapping the intellectual structure, research trends, and knowledge evolution of mobile technologies in predictive maintenance applications from 2016 to 2025. Using systematic methodology adhering to PRISMA guidelines, 167 peer-reviewed publications were extracted from the Scopus database and analyzed using advanced bibliometric techniques, including citation analysis, co-authorship networks, keyword co-occurrence mapping, and thematic evolution assessment. The findings reveal exponential research growth from 1 publication in 2016 to 43 publications in 2024, representing a 3,900% increase and indicating rapid field maturation. India emerges as the dominant research contributor (49 publications, 29.3%), followed by the USA (18 publications, 10.8%) and Italy (15 publications, 9.0%), demonstrating significant geographic concentration in Asia-Pacific (39.5%) and European (22.4%) regions. Thematic analysis identifies augmented reality, the Internet of Things, and machine learning as core technological enablers, while co-citation analysis reveals Mourtzis D as the central intellectual hub connecting diverse research streams. The intellectual structure reveals four major research clusters: IoT-enabled mobile sensing, augmented reality applications, machine learning algorithms, and digital twin integration. Strategic thematic mapping positions predictive maintenance, augmented reality, and IoT as motor themes driving field advancement while identifying emerging opportunities in the industrial metaverse and 6G technologies. International collaboration analysis reveals hub-and-spoke patterns centred on India, with limited cross-cluster integration suggesting opportunities for enhanced global knowledge exchange. This bibliometric analysis provides the first comprehensive mapping of the mobile predictive maintenance (PdM) research landscape, offering evidence-based insights for researchers, practitioners, and policymakers navigating the evolving intersection of mobile technologies and smart manufacturing systems in Industry 4.0 contexts.

Jabeen, S., Sikandar, H., Khan, M. M., Sikandar, K. (2025). Mobile Technologies in Predictive Maintenance for Industry 4.0: A Bibliometric Analysis of Research Trends, Knowledge Structure, and Future Directions. *International Journal of Interactive Mobile Technologies (iJIM)*, 19(22), pp. 136–153. https://doi.org/10.3991/ijim.v19i22.58227

Article submitted 2025-07-13. Revision uploaded 2025-08-28. Final acceptance 2025-08-31.

KEYWORDS

predictive maintenance (PdM), mobile technologies, Industry 4.0, augmented reality, Internet of Things, bibliometric analysis

1 INTRODUCTION

The Fourth Industrial Revolution has fundamentally transformed manufacturing paradigms through the integration of cyber-physical systems, artificial intelligence, and mobile computing technologies, creating unprecedented opportunities for intelligent and autonomous industrial operations [1] [2] [3]. Within this transformation, predictive maintenance (PdM) has emerged as a cornerstone strategy for enhancing operational efficiency, reducing unplanned downtime, and optimizing asset lifecycle management through data-driven decision-making approaches [4] [5]. The convergence of mobile technologies, including smartphones, tablets, augmented reality devices, and wearable sensors—with PdM systems represents a paradigmatic shift toward intelligent, real-time, and location-independent maintenance operations that transcend traditional maintenance boundaries [6] [7] [8].

The relevance of mobile technologies in predictive maintenance stems from multiple converging technological and organizational factors. Modern mobile devices possess computational capabilities and sensor arrays that enable sophisticated industrial applications, from real-time vibration analysis to visual inspection through augmented reality interfaces [9] [6]. The proliferation of the Industrial Internet of Things (IIoT) has generated massive volumes of maintenance-relevant data requiring accessible, intuitive interfaces for field technicians and maintenance managers, positioning mobile platforms as critical integration points for complex industrial ecosystems [10].

Recent global events have further accelerated mobile PdM adoption, as organizations sought to minimize physical presence while maintaining operational continuity, demonstrating the strategic importance of remote diagnostic capabilities enabled by mobile platforms [11] [12]. This trend has persisted, with organizations recognizing the operational advantages of mobile-enabled maintenance systems in enhancing workforce flexibility, reducing response times, and enabling expert knowledge sharing across distributed facilities [13].

Despite the growing technological and industrial significance of mobile predictive maintenance, the research landscape remains fragmented, with several critical knowledge gaps persisting. First, existing literature lacks comprehensive bibliometric analysis of how mobile technologies integrate within broader Industry 4.0 predictive maintenance ecosystems [14]. While individual studies demonstrate specific applications and implementations, systematic analysis of research trends, intellectual structure, and knowledge evolution patterns remains absent from the literature.

Second, there is insufficient understanding of the geographic distribution and collaboration patterns shaping mobile PdM research development. The rapid emergence of research contributions from diverse international contexts, particularly from emerging economies, requires systematic analysis to understand innovation patterns and knowledge transfer mechanisms [15] [16]. Current research provides limited insights into how different national contexts, industrial policies, and technological capabilities influence mobile PdM research directions and practical implementations.

Third, thematic evolution and technological convergence patterns between mobile platforms and core Industry 4.0 technologies, including digital twins, machine learning algorithms, and cyber-physical systems, require systematic investigation [17] [18]. While individual studies explore specific technology combinations, comprehensive analysis of how these convergence patterns evolve temporally, and influence research trajectories remain underexplored.

Finally, the intellectual structure and scholarly influence patterns within mobile PdM research communities require systematic mapping to understand knowledge flow, identify key contributors, and reveal collaboration opportunities [19] [20]. Rapid field expansion necessitates bibliometric approaches to navigate the expanding literature and identify strategic research positioning opportunities.

Figure 1 presents the conceptual framework underlying this bibliometric analysis, demonstrating the convergence of mobile technologies with predictive maintenance capabilities within Industry 4.0 contexts. The framework positions mobile devices (smartphones, AR/VR, tablets, and wearables) as enablers of enhanced predictive maintenance processes, which in turn drive smart manufacturing optimization through digital twins, quality control systems, cost reduction strategies, and zero-downtime operations.

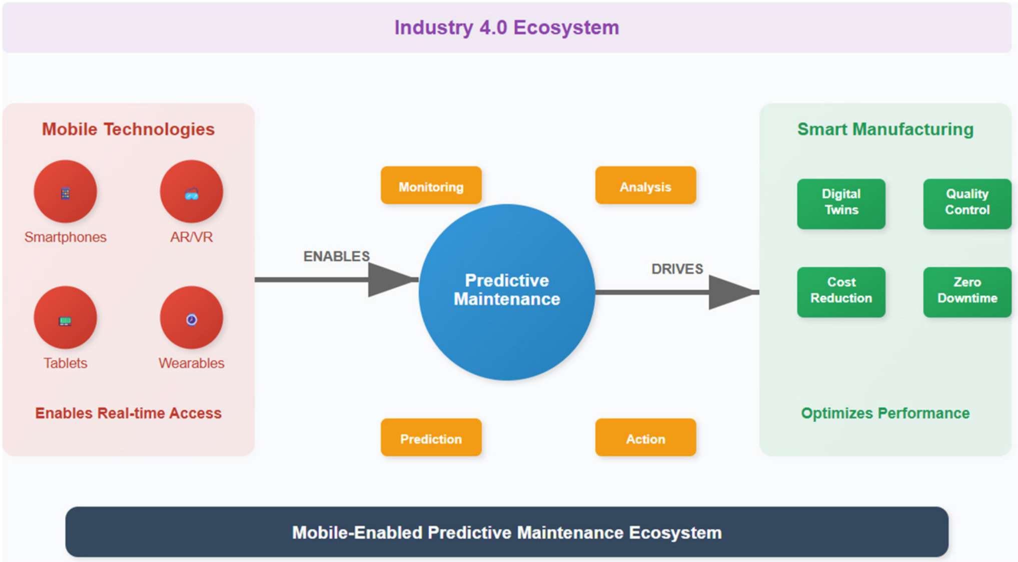

Fig. 1. The conceptual framework

This bibliometric analysis addresses the gaps in the literature by providing the first comprehensive mapping of mobile technologies' role in predictive maintenance research within Industry 4.0 contexts. The study pursues four primary research objectives:

- Map research evolution and growth patterns in mobile PdM from 2016–2025, identifying temporal phases, geographic distributions, and productivity patterns
- Analyze intellectual structure and knowledge networks through co-citation analysis, collaboration patterns, and scholarly influence mapping
- Identify thematic structure and technological convergence via keyword evolution, co-word networks, and strategic theme positioning
- Determine research gaps and future directions to guide scholarly efforts and practical implementations

The study makes theoretical, methodological, and practical contributions. Theoretically, it advances understanding of bibliometric patterns in emerging domains, showing how mobile technologies act as integration platforms within Industry 4.0. Methodologically, it demonstrates how bibliometric techniques can map technological convergence, offering a framework for other interdisciplinary fields. Practically, it provides evidence-based insights for key stakeholders: researchers gain guidance on collaboration and emerging themes; practitioners receive intelligence on trends, institutions, and implementation patterns; and policymakers obtain insights on geographic concentration and collaboration to inform technology transfer and innovation policy.

2 METHODOLOGY

This study employs a bibliometric analysis to explore the integration of mobile technologies in predictive maintenance within the Industry 4.0 paradigm. The methodology adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, reproducibility, and methodological rigor [21]. The approach encompasses literature identification, screening, eligibility assessment, and inclusion, followed by a bibliometric analysis to map research trends, influential works, and knowledge gaps in the field.

The literature search was conducted using the Scopus database, selected for its extensive coverage of peer-reviewed publications in engineering, technology, and interdisciplinary fields relevant to Industry 4.0 [22]. A comprehensive search string was developed using three main keyword clusters: predictive maintenance terms ("predictive maintenance," "condition-based maintenance," "prognostics and health management"), mobile technology terms ("mobile technology," "mobile device," "smartphone," "tablet," "wearable device," "augmented reality," "mobile IoT"), and Industry 4.0 terms ("Industry 4.0," "smart manufacturing," "smart factory," "cyber-physical systems," "digital twins," "IoT," "Internet of Things"). This query targeted documents published between 2016 and 2025, restricted to articles (ar), conference papers (cp), book chapters (ch), and reviews (re) in English, from journals, conference proceedings, books, or series, ensuring relevance to the research scope.

Data from the 167 included studies were extracted, including publication year, authorship, affiliations, keywords, and citation counts. The bibliometric analysis utilized the R programming language with the bibliometrix package to visualize co-authorship networks, keyword co-occurrences, and citation patterns, enabling the identification of research clusters, influential authors, and emerging trends (Aria and Cuccurullo, 2017). The systematic approach begins with data collection from the Scopus database, followed by rigorous PRISMA filtering that reduced 189 initial records to a final dataset of 167 publications. The subsequent analysis employed R Bibliometrix software to examine multiple dimensions, including production patterns, citation analysis, author productivity, geographic distribution, keyword evolution, and source characteristics. Advanced network analysis techniques, including co-citation, co-word, collaboration networks, and strategic thematic mapping, were integrated to provide comprehensive insights into the intellectual structure and research landscape of mobile predictive maintenance in Industry 4.0 contexts.

The bibliometric analysis synthesized findings on the application of mobile technologies in predictive maintenance, focusing on technological frameworks, implementation challenges, and Industry 4.0 integration. The bibliometric analysis utilized R Studio to visualize co-authorship networks, keyword co-occurrences, and citation patterns, enabling the identification of research clusters, influential authors, and emerging trends. This dual approach ensured a comprehensive understanding of the research landscape and its intellectual structure.

Figure 2 illustrates the study selection process following PRISMA 2020 guidelines. The diagram details the number of records identified, screened, assessed for eligibility, and included, providing a transparent overview of the filtering stages.

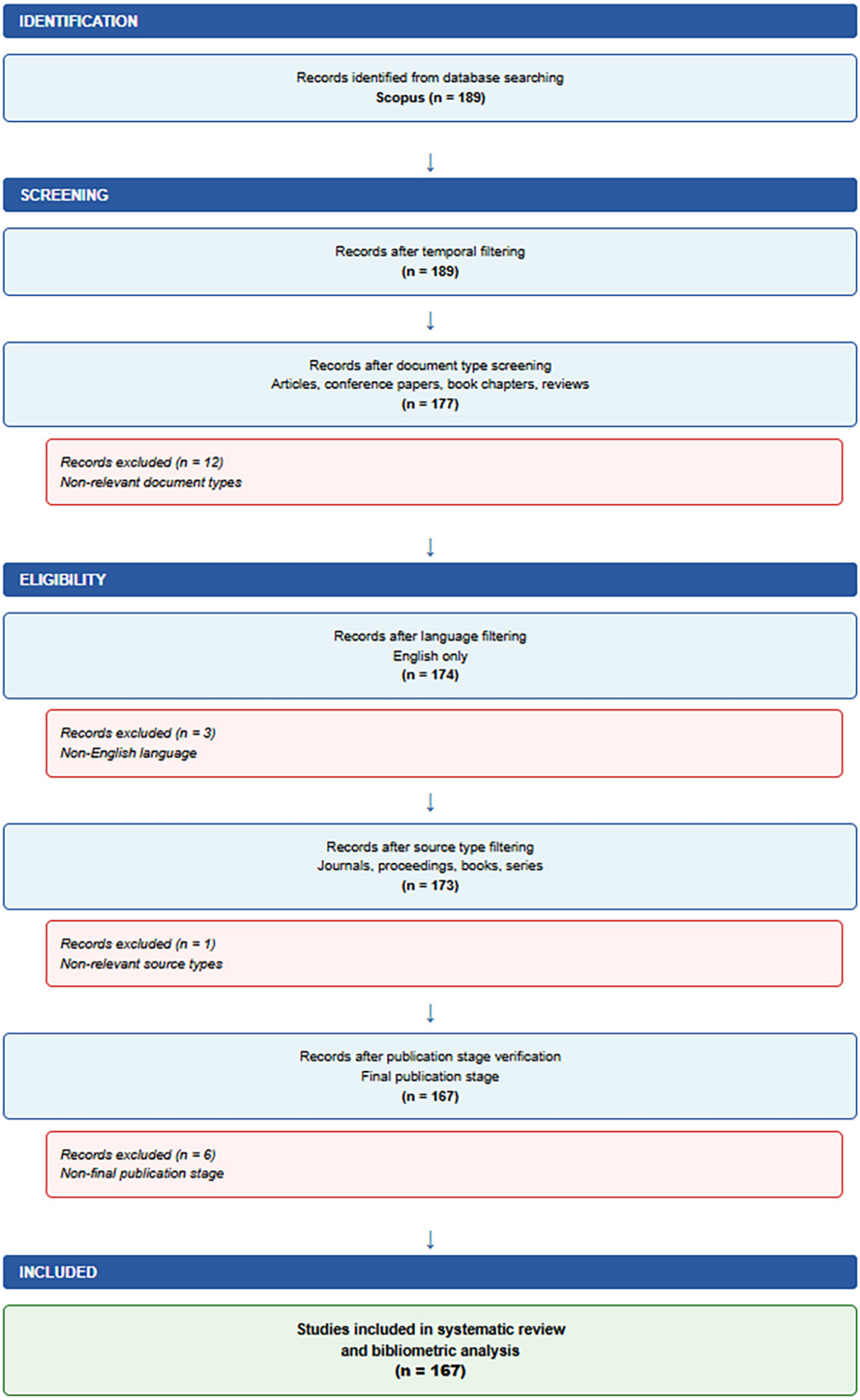

Fig. 2. The study selection process following PRISMA 2020 guidelines

3 RESULTS

3.1 Descriptive statistics

Growth production output. Figure 3 illustrates the annual and cumulative publication trends from 2016 to 2025, highlighting the evolution of research in predictive maintenance integrated with mobile technologies for Industry 4.0 applications. The analysis reveals remarkable growth from a single publication in 2016 to 167 total publications by 2025, representing a 3,900% increase over the study period. The blue line represents the annual number of publications, showing a gradual increase from just 1 paper in 2016 to 39 in 2025, with a notable peak of 43 publications in 2024. This surge reflects growing academic and industrial interest in mobile-based predictive maintenance solutions, particularly as Industry 4.0 technologies such as IoT, digital twins, and cyber-physical systems gained traction.

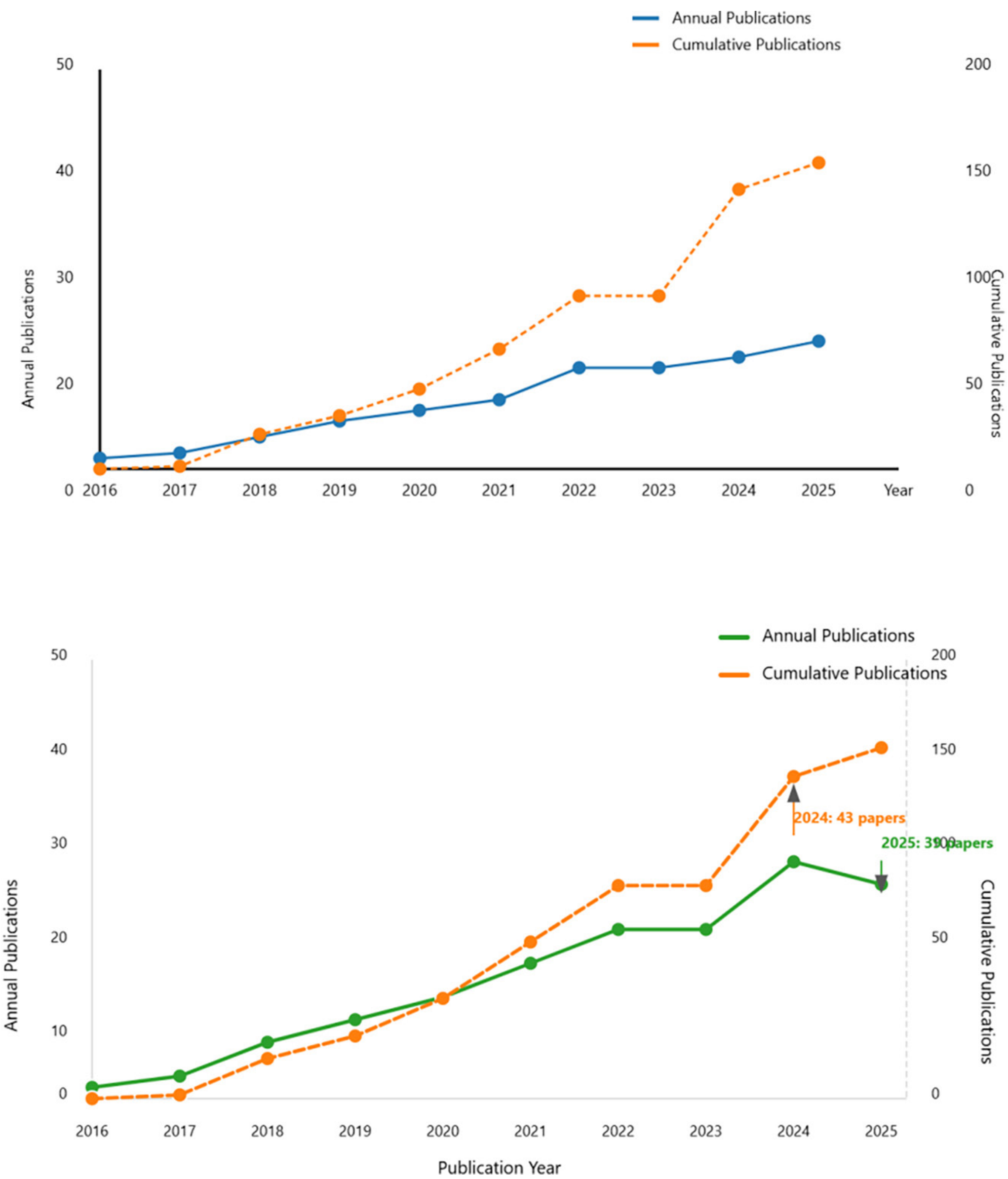

Fig. 3. Annual and cumulative publication trends (2016–2025)

The orange dashed line tracks cumulative publications, revealing an exponential rise after 2021 and reaching 167 papers by 2025. This trend underscores the field's rapid development and maturation, with the steepest growth occurring between 2023 and 2024, likely driven by advancements in mobile IoT, augmented reality, and smart manufacturing. The post-2020 acceleration aligns with broader adoption of AI and edge computing in industrial maintenance, coinciding with enhanced mobile computing capabilities, 5G deployment, and post-COVID digital transformation initiatives. Figure 3 illustrates annual and cumulative publication trends from 2016 to 2025, revealing exponential growth from 1 publication in 2016 to 167 by 2025 (a 3,900% increase). The peak production year was 2024 with 43 publications, while cumulative data shows accelerated growth after 2021. This surge reflects growing academic and industrial interest in mobile PdM solutions, driven by Industry 4.0 technology maturation. Four temporal phases emerge: emergence (2016–2018), growth (2019–2021), expansion (2022–2023), and maturation (2024–2025), with 49.1% of total publications concentrated in the final two years. The post-2020 acceleration aligns with AI, edge computing adoption, and post-COVID digital transformation, validating the timeliness and increasing importance of mobile technologies in Industry 4.0 predictive maintenance.

Leading authors and countries. The bibliometric analysis reveals distinct patterns in author productivity and geographic distribution of mobile PdM research (refer to Table 1). Author analysis demonstrates highly distributed research participation, while geographic analysis shows significant regional concentration, reflecting different national priorities and technological capabilities in Industry 4.0 adoption.

Table 1. Most productive authors

Rank	Author	Papers	Country	Research Focus
1	Romero, L.	4	Spain	AR applications
2	Moreira, P.M.	3	Portugal	IoT integration
2	Zenisek, J.	3	Austria	Smart manufacturing
4	Kumar, A.	2	India	Machine learning
4	Yang, S.	2	China	Mobile sensors
4	Rey, W.P.	2	Germany	Industry 4.0
4	Bengtsson, M.	2	Sweden	Predictive analytics
4	Sharma, M.	2	India	Mobile applications

Author productivity analysis (refer to Table 1) reveals limited research concentration among individual researchers. Romero, L., from Spain, leads with four publications focusing on augmented reality applications, followed by Moreira, P.M. (Portugal, IoT integration) and Zenisek, J. (Austria, smart manufacturing) with three publications each. Only 15 authors (12.6%) have multiple publications, while 87.4% contribute single papers, indicating an emerging field without established research clusters or dominant research groups. This distribution pattern suggests broad international participation rather than concentrated expertise, typical of rapidly evolving technological domains.

Table 2. Leading countries by publications

Rank	Country	Papers	%	Key Focus
1	India	49	29.3%	IoT, ML algorithms
2	USA	18	10.8%	Digital twins
3	Italy	15	9.0%	AR, smart manufacturing
4	China	13	7.8%	Industrial IoT
5	UK	10	6.0%	Predictive analytics
6	Germany	9	5.4%	Industry 4.0
7	France	5	3.0%	Mobile robotics
8	South Korea	4	2.4%	Smart factories

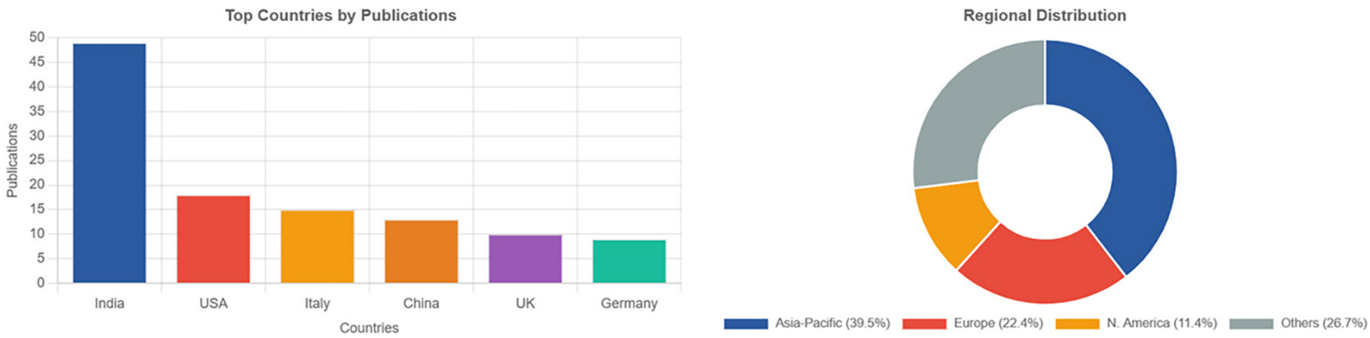

Fig. 4. Global research distribution

Geographic distribution (see Figure 4 and Table 2) reveals pronounced research concentration with India dominating at 49 publications (29.3%), reflecting strategic national digital manufacturing initiatives and focus on cost-effective IoT and machine learning solutions. The USA (18 papers, 10.8%) emphasizes advanced digital twin technologies, while Italy (15 papers, 9.0%) concentrates on augmented reality and smart manufacturing applications. China (13 papers, 7.8%) focuses on IIoT implementations.

Regional analysis shows Asia-Pacific leadership (39.5%), followed by Europe (22.4%) and North America (11.4%). The top six countries produce 68.3% of all research, indicating concentrated activity in major industrial nations. This geographic concentration reflects national Industry 4.0 policies, research funding priorities, and industrial infrastructure capabilities. However, the analysis reveals limited international collaboration, with most research conducted within single-country teams, suggesting opportunities for enhanced global knowledge exchange in mobile PdM development.

Subject area analysis. Subject area analysis reveals (see Figure 5) the interdisciplinary nature of mobile PdM research spanning 20+ domains. Computer Science (109 publications, 27.5%) and Engineering (103 publications, 26.0%) dominate, collectively representing 53.5% of research output and reflecting the core technological foundations. Mathematics (31 publications, 7.8%) and Decision Sciences (20 publications, 5.1%) provide supporting analytical frameworks, while Energy (28 publications, 7.1%) represents the primary application domain. The presence of Social Sciences (15 publications, 3.8%) and Business Management (14 publications, 3.5%) indicates emerging recognition of human factors, though technology-driven research clearly predominates. This distribution demonstrates mobile PdM as a fundamentally interdisciplinary field requiring convergence of computer science algorithms, engineering applications, and mathematical modeling.

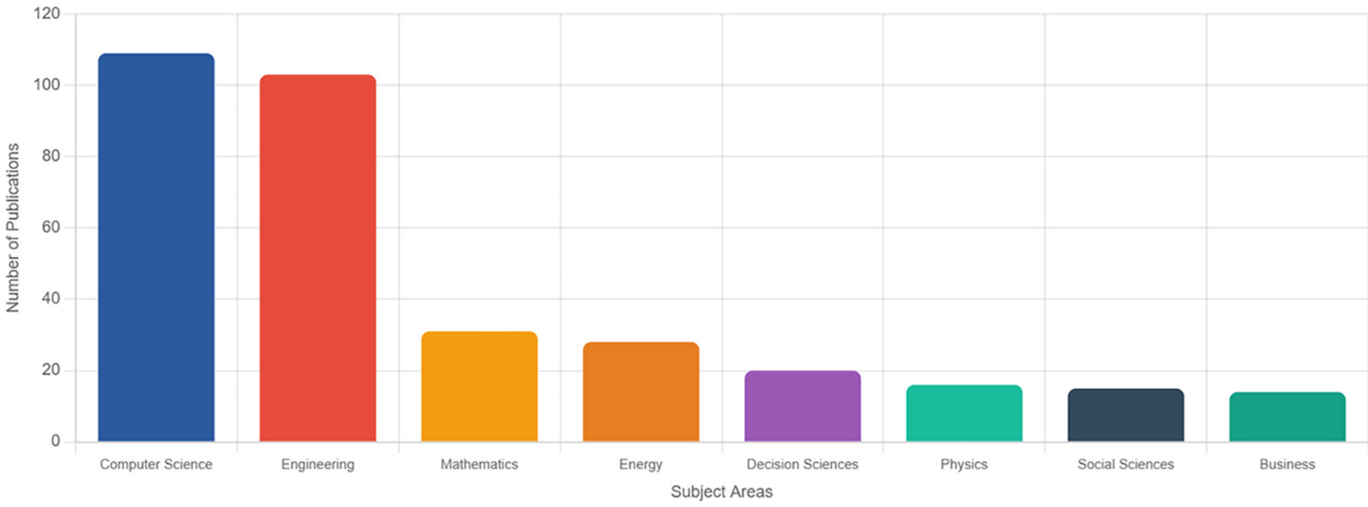

Fig. 5. Subject area analysis

Leading academic journals and publication venues. Publication source analysis (see Figure 6) reveals highly distributed publishing patterns characteristic of an emerging interdisciplinary field. The top source, *Lecture Notes in Networks and Systems*, accounts for only seven publications (4.2%), indicating no dominant publication venue. Conference proceedings dominate with seven of the top 10 sources, reflecting the field's dynamic and rapidly evolving nature. Springer emerges as the leading publisher with three of the top five sources, followed by Elsevier and IEEE. The distribution spans multiple engineering domains, including networks, electrical, mechanical, and computer science, demonstrating the interdisciplinary breadth of mobile PdM research.

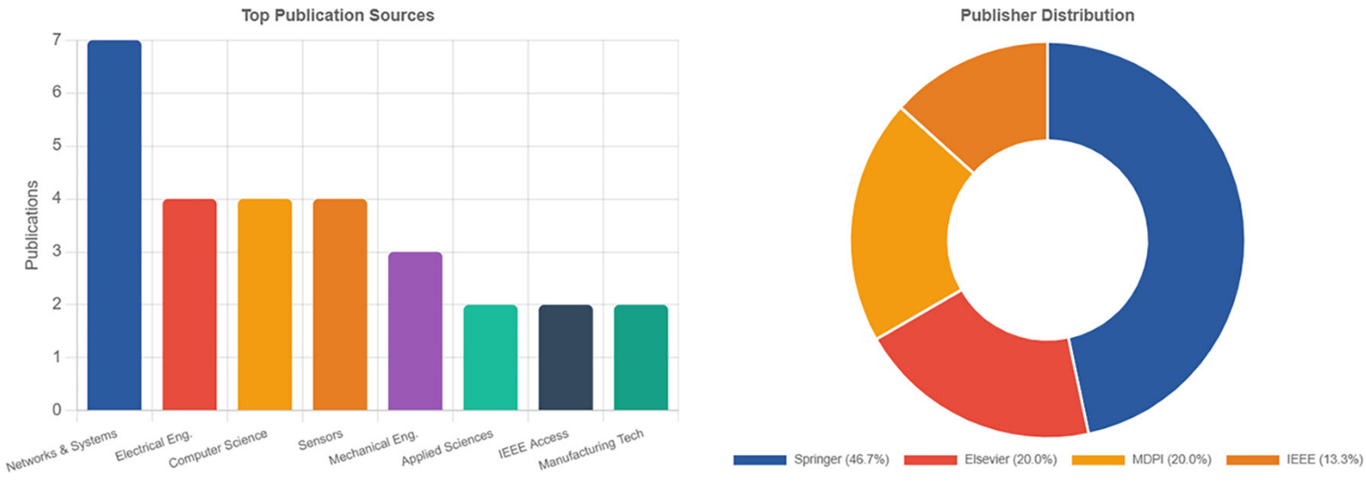

Fig. 6. Publication source analysis

3.2 Keyword evolution and thematic trend analysis

Most relevant keywords and research focus. Figure 7 reveals the dominant research themes through keyword frequency analysis, with "predictive maintenance" emerging as the central concept with 97 occurrences, confirming its position as the core research domain. "Augmented reality" follows with 55 occurrences, establishing AR as the dominant mobile technology in PdM applications. "Internet of Things" (47 occurrences) and "maintenance" (27 occurrences) complete the top-tier keywords, while "Industry 4.0" (21 occurrences) and "machine learning" (15 occurrences) represent key technological enablers.

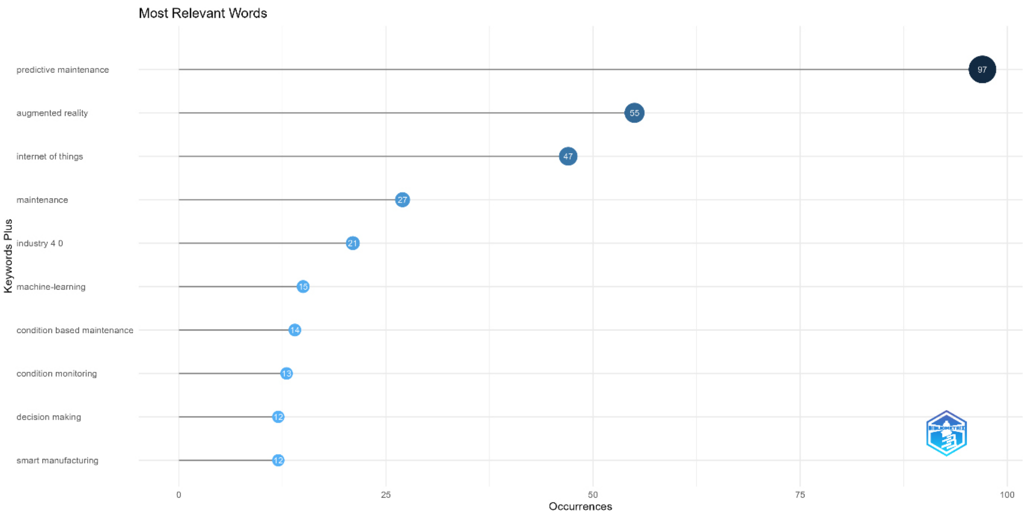

Fig. 7. The dominant research themes

The keyword distribution reveals three primary research clusters: mobile visualization technologies (augmented reality, smart manufacturing), connectivity and data infrastructure (IoT, Industry 4.0), and analytical capabilities (machine learning, decision making, condition monitoring). This clustering pattern indicates convergent research focusing on integrated mobile-enabled PdM solutions rather than isolated technological developments.

While keyword frequency analysis reveals dominant themes, examining their temporal evolution provides insights into how research priorities have shifted over time.

Thematic convergence and research maturation. The bubble size variations in trending topics (see Figure 8) reveal research intensity and temporal concentration patterns. Predictive maintenance maintains consistent presence throughout the timeline with peak intensity in recent years, while augmented reality shows concentrated development in the 2020–2022 period, suggesting rapid technological advancement and practical implementation. Smart manufacturing, digital twins, and IoT clusters are at the timeline's end, indicating current and future research directions. This temporal clustering suggests field evolution from reactive to predictive to intelligent maintenance paradigms, enabled by mobile technology integration. The keyword co-occurrence patterns demonstrate interdisciplinary convergence, with mobile technologies serving as integration platforms connecting traditional maintenance concepts with advanced Industry 4.0 capabilities. This convergence pattern validates mobile PdM as a synthesizing domain rather than a standalone technology area. Beyond thematic analysis, understanding the intellectual structure of mobile PdM research requires examination of citation patterns and scholarly influence networks.

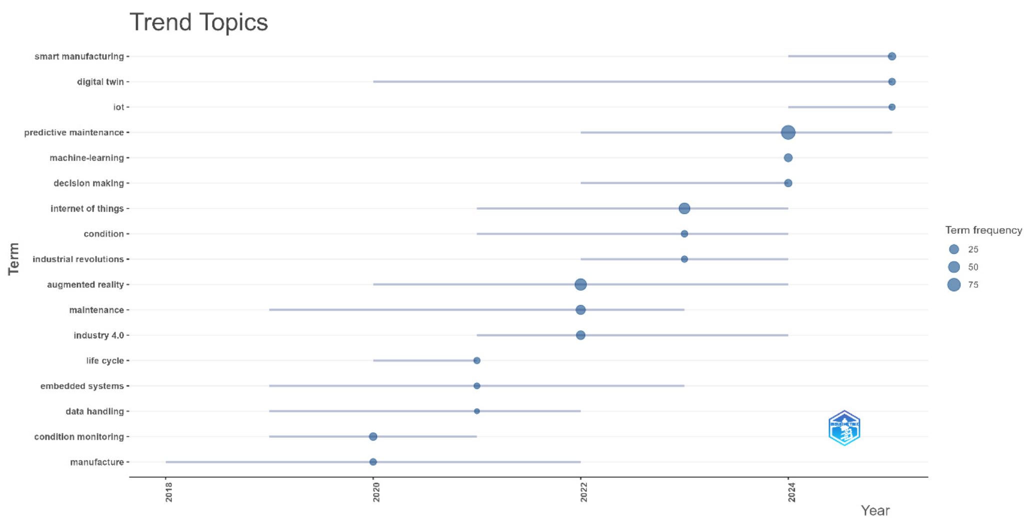

Fig. 8. Trending topics

Co-citation network analysis and intellectual structure. Figure 9 presents the co-citation network revealing the intellectual structure and scholarly influence patterns in mobile predictive maintenance research. The network visualizes cited authors clustered by co-occurrence patterns, with node sizes reflecting citation frequency and colors representing distinct research communities. Mourtzis D emerges as the central intellectual hub with the highest betweenness centrality (262.509) and PageRank score (0.075), positioning him as the most influential knowledge broker connecting diverse research streams in mobile manufacturing and maintenance technologies. Lee J and Tao F follow as secondary hubs, indicating their foundational contributions to Industry 4.0 and digital twin research, respectively. The dense central core suggests established theoretical foundations with recognized authorities and canonical references.

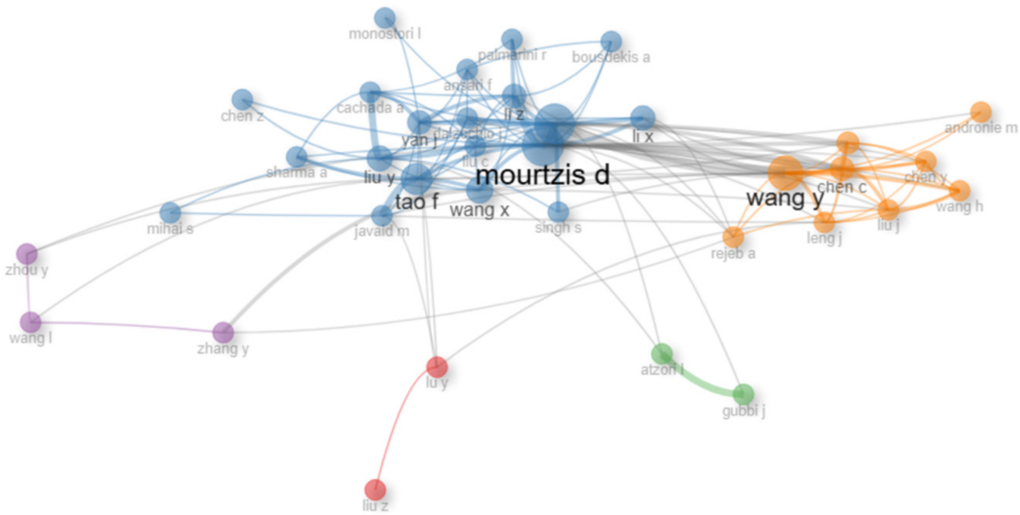

Fig. 9. The co-citation network

Five distinct research clusters emerge through color coding: the dominant blue cluster (Mourtzis D, Tao F, Lee J) represents mainstream mobile manufacturing and Industry 4.0 research; the orange cluster (Wang Y, Chen C, Wang H) indicates Chinese research contributions focusing on IoT and mobile sensor technologies; while smaller purple, red, and green clusters suggest specialized research niches and emerging interdisciplinary contributions from networking and data analytics domains.

Network structure characteristics indicate field maturity through high interconnectedness among central nodes, representing mature scholarly discourse, while peripheral expansion shows dynamic research growth and new contributor integration. The strong bridge connections between clusters suggest interdisciplinary integration and knowledge transfer across different research approaches, validating mobile PdM as a convergent field with strategic collaboration opportunities across distinct research communities. While co-citation analysis reveals the intellectual structure through author relationships, co-word analysis examines the conceptual structure through keyword relationships and thematic clustering.

Co-word network analysis and thematic structure. Figure 10 presents the co-word network analysis revealing thematic relationships and conceptual structure within mobile predictive maintenance research. "Predictive maintenance" dominates as the central hub, confirming its role as the primary research focus, with multiple thematic clusters radiating outward representing specialized research domains.

Five distinct thematic clusters emerge through color coding: the blue cluster represents core maintenance concepts (maintenance, condition monitoring, real-time systems, embedded systems); the red cluster encompasses AI and machine learning technologies (machine learning, artificial intelligence, deep learning, neural networks); the green cluster focuses on mobile technologies (smartphones, augmented reality, inspection, condition-based maintenance); the orange cluster covers analytics and decision support (predictive analytics, condition monitoring, industrial revolutions); while the purple cluster addresses data management (data analytics, data handling, preventive maintenance).

Key bridge concepts connect different thematic areas: "maintenance" and "IoT" serve as primary connectors linking traditional maintenance with modern technologies; "augmented reality" bridges mobile technologies with visualization applications; "machine learning" connects AI capabilities with predictive analytics; and "manufacturing industries" links technological concepts with application domains. The network density around central concepts indicates mature research integration, while peripheral specialized terms (5G mobile communication, network security, virtual environments) suggest emerging research directions and technological convergence opportunities in mobile PdM applications.

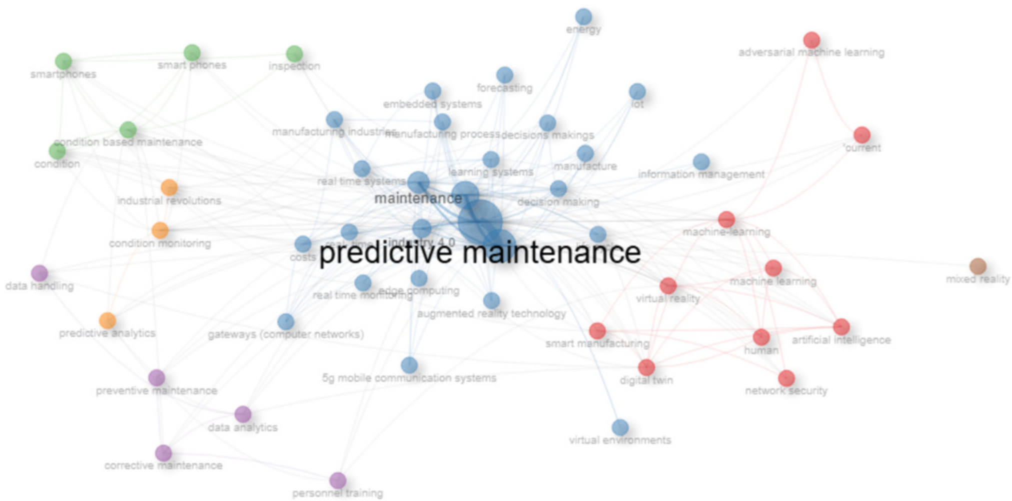

Fig. 10. The co-occurrence of keywords network

Thematic map analysis and strategic research positioning. Figure 11 presents the thematic map analysis using centrality-density positioning to identify research themes' strategic importance and development maturity. The four-quadrant framework reveals distinct research categories based on relevance degree (centrality) and development degree (density).

Motor themes (upper-right quadrant) represent well-developed and central research areas driving the field forward. "Predictive maintenance," "augmented reality," and "internet of things" occupy this strategic position, indicating they are both highly relevant and internally well-developed, serving as primary research drivers with strong theoretical foundations and practical applications. These themes represent the core research agenda with established methodologies and active scholarly communities.

Niche themes (upper-left quadrant) include specialized, well-developed but peripheral topics such as "manufacture," "IoT technologies," "smart grids," and "data visualization." These represent highly specialized research areas with internal coherence but limited broader field impact, suggesting expert-driven research domains with focused applications.

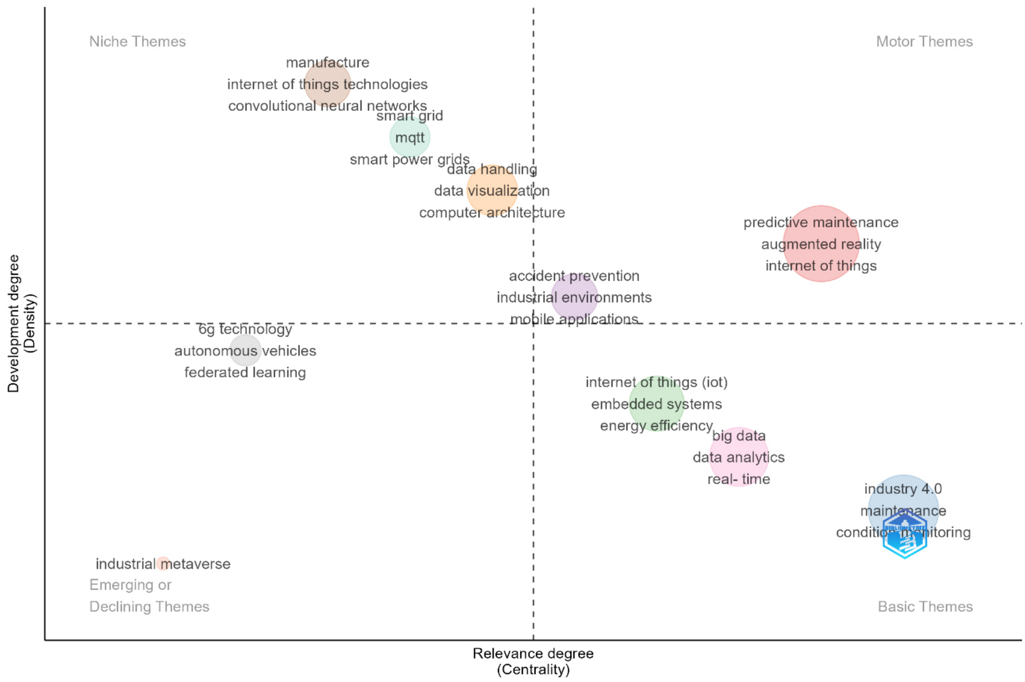

Fig. 11. Thematic map analysis

Basic themes (lower-right quadrant) encompass fundamental but underdeveloped concepts including "Industry 4.0," "maintenance," "condition monitoring," and "big data." These themes are centrally important but lack internal development, representing foundational concepts requiring further research integration and methodological advancement. Emerging or declining themes (lower-left quadrant) feature "industrial metaverse," "6G technology," and "autonomous vehicles," representing either nascent research areas with future potential or declining topics losing research momentum. The positioning suggests strategic opportunities for researchers to develop these themes or research areas requiring revitalization through new theoretical or methodological approaches. Complementing the intellectual and thematic structure analysis, examination of international collaboration patterns reveals the global research networks and partnership dynamics in mobile PdM research.

International collaboration network analysis. Figure 12 presents the international collaboration network, revealing global research partnerships and geographic clustering patterns in mobile predictive maintenance research. India dominates as the central collaboration hub with the highest betweenness centrality (183.935) and PageRank score (0.11), positioning it as the primary bridge connecting diverse international research communities.

Five distinct collaboration clusters emerge: Cluster 1 (red) centers around India-USA-Germany collaboration with extended partnerships including France, Slovakia, Korea, and Czech Republic, representing a transatlantic research alliance combining Indian innovation, American technology leadership, and European industrial expertise. Cluster 2 (blue) forms an Asia-Pacific and Middle Eastern network led by China-Malaysia collaboration (betweenness: 37.813 and 61.705, respectively), including Ukraine, Indonesia, Saudi Arabia, and UAE, suggesting regional technology transfer and emerging market partnerships. Cluster 3 (green) represents a Commonwealth research network connecting the UK and Portugal with African partners (South Africa, Nigeria, and Poland), indicating historical ties and development-focused collaborations. Smaller clusters include Italy-Greece partnerships (purple), reflecting Mediterranean cooperation, and isolated Nordic countries (Norway, Turkey) with limited international connections.

The network structure reveals hub-and-spoke patterns rather than dense multilateral collaborations, with India serving as the primary global connector linking different regional clusters. Limited cross-cluster connections suggest missed opportunities for broader international knowledge exchange, while peripheral positioning of some countries (Philippines, Nigeria, Norway) indicates potential for expanded collaboration networks in mobile PdM research development.

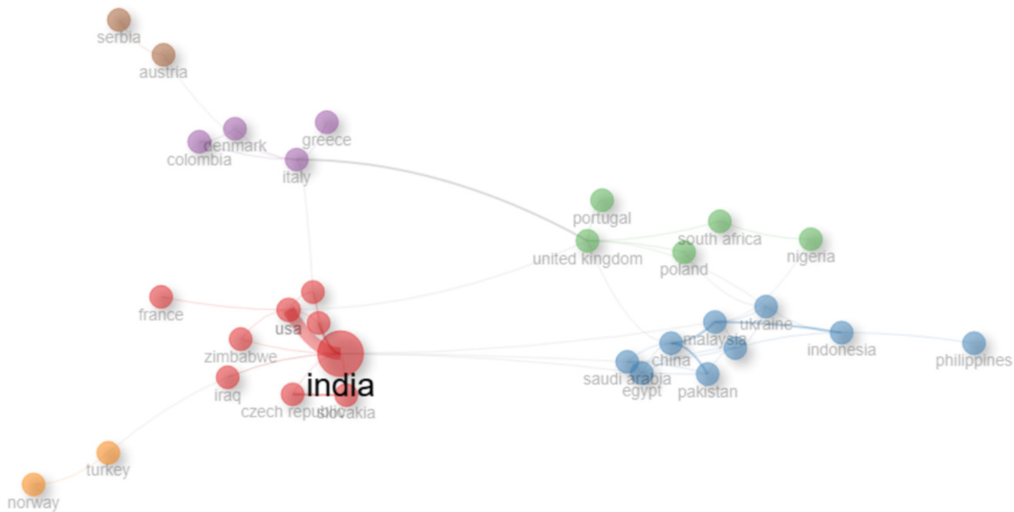

Fig. 12. International collaboration network

4 DISCUSSION

This bibliometric analysis shows mobile predictive maintenance as a rapidly expanding domain, with 3,900% growth from 2016 to 2025 reflecting its shift from exploratory research to mainstream focus, driven by Industry 4.0 and post-COVID digital transformation. This growth highlights fundamental changes in how maintenance integrates with mobile technologies to meet industrial challenges.

The methodological approach demonstrates the value of bibliometric analysis in capturing technological convergence through co-citation, thematic mapping, and collaboration networks. Combining production analysis with intellectual structure and geographic mapping reveals how research growth aligns with scholarly influence, while also exposing gaps between high research productivity and limited international collaboration.

Geographically, India leads with 29.3% of publications, reflecting national digital manufacturing policies, while the broader Asia-Pacific accounts for 39.5%. Traditional leaders like the USA and Germany remain influential through advanced applications, signaling a shift in innovation geography toward emerging economies. Intellectual structure analysis identifies Mourtzis D as the central knowledge broker, with five distinct research clusters showing methodological diversity but limited integration, underscoring the need for cohesive frameworks.

Thematic evolution shows four phases: emergence (2016–2018), growth (2019–2021, with IoT and AR), expansion (2022–2023, convergence with smart manufacturing), and maturation (2024–2025, advanced AI). Augmented reality dominates mobile interfaces, while machine learning underpins predictive capabilities. Thematic mapping positions predictive maintenance, AR, and IoT as motor themes, while Industry 4.0 and condition monitoring require further development, and the industrial metaverse and 6G represent emerging opportunities.

Collaboration patterns remain hub-and-spoke, concentrated in India, with limited multilateral partnerships, while conferences dominate publication outlets (57.4%), reflecting the field's dynamism but also limited synthesis efforts. Citation analysis shows peak influence in 2021 (40.9 citations per article), with recent publications under-cited due to recency effects; overall average citations (10.5) indicate moderate but growing scholarly impact typical of emerging technical fields.

5 CONCLUSION

This framework offers a robust basis for understanding technological evolution with applicability to other emerging domains. The analysis shows mobile technologies function as integration platforms linking traditional maintenance with Industry 4.0, positioning them as central coordination mechanisms in smart manufacturing rather than peripheral add-ons. The convergence of AR, IoT, and machine learning highlights the technological complementarity needed for comprehensive predictive maintenance systems. Strategic insights include India's unexpected research leadership, reshaping assumptions about innovation geography, and hub-and-spoke collaboration patterns that highlight the need for stronger international partnerships. Thematic mapping identifies clear priorities, including the industrial metaverse and next-generation connectivity.

Practical implications extend to researchers, practitioners, and policymakers. Researchers gain guidance on collaboration and thematic positioning; practitioners obtain intelligence on technological trends and implementation pathways; policymakers can use geographic insights to support innovation strategies and global cooperation. The field's maturation signals a shift from exploration to implementation, creating opportunities for industrial application while maintaining the need for theoretical development. These findings provide evidence-based direction for stakeholders navigating the fast-evolving landscape of mobile predictive maintenance.

6 LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

These findings face several methodological limitations. Reliance on Scopus may exclude regional or specialized publications, while the English-language focus overlooks important non-English research. Publication lag leaves 2024–2025 data incomplete, keyword searches risk missing interdisciplinary work, and citation analysis is shaped by coverage and self-citation biases. The 2016–2025 scope omits earlier foundations, while fast-evolving technologies and informal collaborations remain underrepresented. Future research should explore 5G and edge computing for ultra-low latency, edge AI, and industrial IoT. Sustainability is a neglected area, requiring studies on energy-efficient systems, lifecycle assessments, and circular economy strategies. Cybersecurity and data privacy demand secure infrastructures, advanced encryption, and privacy-preserving analytics. Greater focus on SMEs is needed through scalable, cost-effective solutions, while sector-specific research in aerospace, automotive, and renewable energy is sparse. Human-technology interaction also requires attention to interface design, cognitive load, and workforce training. Methodological advances should include longitudinal studies, cross-cultural comparisons, and interdisciplinary approaches linking predictive maintenance with organizational and socio-economic factors. These directions call for a more integrated agenda to move mobile predictive maintenance from possibility to widespread industrial practice.

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8 AUTHORS

Samrena Jabeen is with the Arab Open University, A'ali, Bahrain (E-mail: samrena.jabeen@aou.org.bh).

Huma Sikandar is with the Abbottabad University of Science and Technology, Havelian, Pakistan (E-mail: huma.sikandar@gmail.com).

Muhammad Muddassar Khan is with the Abbottabad University of Science and Technology, Havelian, Pakistan (E-mail: hodmanagement@aust.edu.pk).

Khadija Sikandar is with the National University of Sciences & Technology, Islamabad, Pakistan (E-mail: Khadija.sikandar@gmail.com).