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Digital Twin Integration in Field Service Management: A Hybrid Systematic Literature Review and Bibliometric Analysis (2017-2024)

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ABSTRACT

Field Service Management (FSM) is undergoing a significant transformation through digital twin technology integration. This study employs a hybrid methodological framework combining systematic literature review (SLR) and bibliometric analysis to examine 166 scholarly publications from 2017-2024. Our findings reveal: (1) a 23.7% compound annual growth rate in FSM research with distinct evolution phases from basic digitization to intelligent integration; (2) digital twin technology emerging as the most transformative innovation in FSM, enabling unprecedented 99.9% network uptime in telecommunications infrastructure; (3) a three-stage maturity model for digital twin implementation (virtual modeling, real-time synchronization, predictive optimization); and (4) implementation barriers including technological integration challenges (38.5%) and organizational resistance (32.4%). The research identifies artificial intelligence integration (42.8%) and autonomous service delivery (35.6%) as dominant future directions for digital twin applications in FSM. This study contributes to information systems theory by mapping the intellectual structure of FSM knowledge and offering the first comprehensive digital twin integration framework for FSM implementation, while providing practitioners with evidence-based strategies for achieving quantifiable operational improvements, particularly in telecommunications infrastructure management.

1. INTRODUCTION

In the current highly competitive digital economy, organizations globally face immense pressure to enhance field service operations while satisfying rising customer expectations. Field Service Management (FSM) has evolved into a vital strategic facilitator, transitioning from conventional reactive maintenance methods to proactive, technology-oriented service ecosystems that incorporate mobile workforces, intelligent assets, and predictive analytics [1, 2].

The convergence of Industry 4.0 technologies, particularly digital twins, Internet of Things (IoT), and artificial intelligence, has radically changed FSM's operational paradigm. This technological evolution represents more than incremental improvement; it signifies a paradigmatic shift toward intelligent, autonomous, and predictive service delivery models that promise to revolutionize how organizations manage field operations across diverse industrial sectors [3, 4].

Recent technology advancements have evolved FSM from fundamental scheduling and dispatching roles to complex ecosystems that incorporate digital twins [5], IoT [6], and artificial intelligence [7]. This evolution signifies the escalating intricacy of field service operations and heightened client expectations for expedited, efficient, and transparent services. This results in a global FSM market anticipated to expand from $3.12 billion in 2018 to $10.81 billion by 2026 [8].

Despite these promising improvements and huge market estimates, a comprehensive evaluation of the existing FSM landscape reveals numerous theoretical and practical gaps that inhibit optimal technology integration and organizational value realization, especially as digital twins [9] are reshaping FSM implementation and results. Contemporary literature primarily emphasizes discrete technology elements or particular industry applications while failing to provide an exhaustive examination of the overarching landscape of FSM research and practice [10]. Furthermore, the rapid evolution of FSM technologies and practices, coupled with changing business requirements and customer expectations, necessitates an up-to-date and comprehensive analysis of FSM implementation trends, challenges, and success factors.

The knowledge deficiency is especially pronounced in the telecommunications sector, where intricate FSM implementations for fiber optic network architecture necessitate advanced systems for multi-layered scheduling, resource allocation, and real-time service delivery oversight [11]. Without a comprehensive understanding of appropriate digital twin integration techniques in Facility Service Management, organizations risk ineffective implementations, resource wastage, and missed opportunities for service excellence.

This research paper fills these gaps by employing a novel hybrid methodology that integrates a systematic literature review (SLR) and bibliometric analysis of 166 articles related to FSM from 2017 to 2024. In contrast to prior studies [12] that focus on specific FSM components, our comprehensive analysis outlines the discipline's intellectual framework, identifies patterns of technological integration, and provides evidence-based recommendations for implementation. We explicitly analyze the revolutionary effects of digital twin technology on FSM results across various industries, with a focus on telecoms infrastructure management, where this integration yields substantial operational enhancements.

In this research also contributes in three significant ways: (1) it delivers the inaugural comprehensive systematic analysis and bibliometric of FSM research, delineating key research clusters, collaboration networks, and knowledge flows; (2) it elucidates detailed insights into the integration patterns and outcomes of digital twin technology in FSM implementation; and (3) it presents evidence-based recommendations for practitioners aiming to enhance field service operations via digital technologies. This research is particularly relevant due to the increasing digitization of corporate processes and the crucial role of efficient field service delivery in maintaining business continuity during challenging times.

This study also proposes the following research topics to address the highlighted gaps and offer a complete overview of the current level of FSM research and implementation, particularly on digital twin integration:

- What are the current trends and developments in FSM research and implementation, particularly regarding digital twin technology integration?
- What are the main drivers behind FSM adoption across industries, and how does digital twin integration influence these adoption decisions?
- What are the major barriers to implementing FSM solutions with advanced technologies like digital twins?
- What are FSM's future research themes and prospects, especially concerning digital twin applications?

2. RESEARCH METHODOLOGY

This study employs a hybrid methodological approach that combines a SLR and bibliometric analysis to thoroughly investigate the development and current status of FSM research, with a particular focus on digital twin integration. This dual methodology presents synergistic advantages: the SLR method, as proposed by Kitchenham and Brereton [13], delivers a comprehensive qualitative evaluation of research themes and outcomes, whereas bibliometric analysis uncovers quantitative trends in research productivity, impact, and collaboration networks [14].

2.1 Research design

The research design follows a rigorous five-stage process: (1) protocol development with precise definition of research scope and questions; (2) comprehensive database search using structured Boolean queries; (3) systematic filtering using explicit inclusion/exclusion criteria; (4) data extraction and quality assessment; and (5) bibliometric analysis and synthesis of findings. This methodological approach enables the identification of overarching trends and patterns in FSM research while enhancing the understanding of the intellectual structure and evolution of digital twin applications in the field.

For the bibliometric component, we utilized VOSviewer, which specializes in creating distance-based maps that visualize co-citation networks, keyword co-occurrence patterns, collaboration networks, and bibliographic coupling relationships [15]. This software enabled sophisticated network visualizations revealing the complex relationships between research themes, particularly digital twin applications in FSM contexts. Figure 1 illustrates the research methodology employed in this study.

2.2 Data collection

The preliminary stage emphasizes a methodical literature review and data extraction, adhering to recognized standards for bibliometric analysis. Table 1 outlines this step, encompassing the thorough definition of the research objective, execution of database searches, systematic filtering of results, and meticulous data cleaning to ensure the quality and relevance of the studied articles.

Table 1. Basic search strategy

Field Service Management: Critical Success Factors, Trends and Challenges				
Field Service	**Management**	**Success Factor**	**Trend**	**Challenge**
Field maintenance Field operation Field support Field worker Onsite service Mobile service Dispatch service	Management	Component Feature Capability	Potential Implementation	Barrier Issue

Use a variety of effective search techniques:
(TITLE-ABS-KEY ("field service" OR "field maintenance" OR "field operation" OR "field support" OR "field worker" OR "onsite service" OR "mobile service" OR "dispatch service") AND TITLE-ABS-KEY (management) AND TITLE-ABS-KEY (success factor OR component OR feature OR capability) AND TITLE-ABS-KEY (trend OR potential OR implementation) AND TITLE-ABS-KEY (challenge OR barrier OR issue)) AND PUBYEAR > 2017
Take advantage of various search tools such *as IEEE Xplore Library, Science Direct, ACM Digital Library, MDPI, Springer Link, Taylor & Francis, Wiley Online Library, Emerald Insight, Scopus and Google Scholar* to find relevant scientific articles.
Establish explicit criteria for assessing the pertinence and caliber of the identified articles. Evaluate factors including publication year,

topic relevancy, research technique, and journal reputation.
Note down the citation information of each article that you think is relevant. This information will be useful for referencing and bibliography creation.

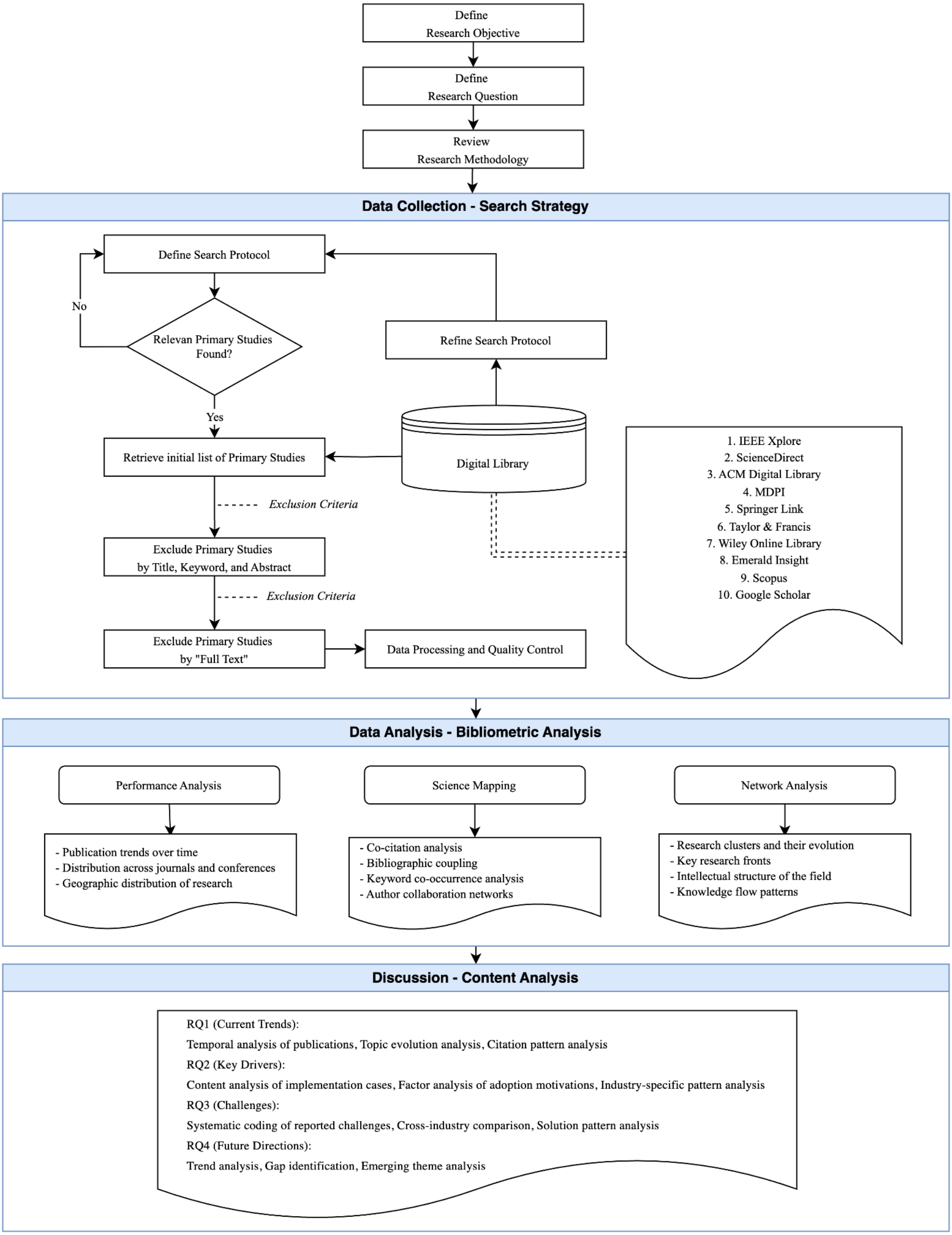

Figure 1. Research methodology for the study

2.2.1 Expand the research protocol

The preliminary phase precisely defines the study topic and establishes the search protocol. Subsequently, ascertain pertinent keywords for the literature search. These keywords will guide to appropriate articles. After getting the main keywords, it is also necessary to look for synonyms or related terms that may be used in the literature. This will help expand the scope of the search.

2.2.2 Use the appropriate search technique

The search strategy was developed through an iterative process, starting with core terms and expanding based on preliminary results. The final search query included the following key terms and their variations. The Boolean search string was also constructed.

2.2.3 Database selection

The research employed ten (10) key academic databases to guarantee extensive coverage. These databases were selected for their comprehensive coverage of scientific papers and their esteemed reputation in the academic world for quality and reliability. The databases were chosen for their extensive coverage of scientific papers and their esteemed reputation in the academic world for quality and reliability.

2.2.4 Information evaluation and citing sources

Establish the evaluation criteria shown in Table 2 and assess the quality of the article. Continues with relevance, topicality, quality of method, and publisher reputation. Then, collect essential data from relevant articles. We explored the research objectives, methodology, results, and conclusions, analyzed the collected data, and synthesized the findings. Ultimately, we can discern patterns, trends, and research deficiencies. The search results were organized and revised with Mendeley Reference Manager, a reference management software. Primary studies were selected using established inclusion and exclusion criteria.

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles and conference proceedings	Non-peer-reviewed articles and book chapters
Publications between 2017 and 2024	Publication before 2017
English language publications	Grey literature (reports, white papers)
Articles focusing on FSM implementation, technologies, or methodologies	Articles not primarily focused and related to service management
Studies related to service operations management in field contexts	Duplicate publications across database

Researchers evaluated the quality, relevance to the research question, and similarity of the original studies alongside the inclusion and exclusion criteria.

The selected articles were thoroughly read, and a quality assessment checklist was employed to evaluate their quality. Duplicate papers authored by the same individuals and published across different sources were eliminated. One hundred and sixty-six (166) studies were retained in the final selection after excluding studies based on a full-text review in all rounds. We were then carefully reviewed and given a further in-depth analysis using bibliometric techniques.

2.2.5 Data processing and quality control

The data processing step established a thorough framework to guarantee the precision and dependability of our bibliometric study. We initiated our approach with meticulous data cleaning and standardization procedures, which are crucial for maintaining data integrity throughout the research process. Initially, we focused on detecting and eliminating duplicate items across multiple databases through automatic DOI matching and manual validation. This technique was essential for identifying conference papers that would later be published as journal articles, necessitating meticulous scrutiny to avoid duplicate counting while maintaining the research's evolutionary character. Standardizing author names became an essential element of our data processing strategy. We implemented a standardized format for author names, tackling the prevalent issue of diverse name variations in academic papers. This procedure involved establishing a comprehensive author database that accommodated various naming practices in global publications, while ensuring the accurate attribution of works to their corresponding authors. Institutional affiliations were meticulously verified to differentiate between authors with identical names, assuring precise attribution of research contributions. This rigorous method of bibliographic standardization was crucial for preserving the integrity of our citation analysis and guaranteeing dependable network visualizations. Quality control measures were meticulously recorded and routinely evaluated to ensure uniformity throughout the study [16]. This thorough methodology for data processing and quality assurance provided a robust basis for our subsequent studies, ensuring the reliability and validity of our results. The rigorous nature of our methodology supports the reproducibility of our results and provides a strong basis for future research [17], especially in the field of FSM.

2.3 Theoretical framework

This study employs a multi-theoretical lens combining the Technology Organization Environment (TOE) framework and the Resource-Based View (RBV) theory to understand digital twin integration in FSM contexts.

2.3.1 TOE framework application

The TOE framework provides a comprehensive lens for analyzing digital twin adoption factors:

1) Technological Context: Digital twin maturity, integration complexity, and compatibility with existing FSM systems.
2) Organizational Context: Firm size, managerial support, resource availability, and organizational readiness for digital transformation.
3) Environmental Context: Industry characteristics, competitive pressure, regulatory requirements, and customer expectations.

2.3.2 Resource-based view (RBV) integration

RBV theory explains how digital twin capabilities create sustainable competitive advantages through:

1) Valuable Resources: Digital twin technology's ability to generate predictive insights and operational efficiencies.
2) Rare Capabilities: Advanced analytics and real-time monitoring competencies that few competitors possess.
3) Inimitable Assets: Organizational learning and knowledge accumulated through digital twin implementation.
4) Non-substitutable Advantages: Integrated digital ecosystems that create a barrier to entry for competitors.

2.3.3 Theoretical synthesis

The integration of TOE and RBV frameworks enables a holistic understanding of how technological, organizational, and environmental factors influence digital twin adoption decisions. At the same time, RBV explains the mechanism through which these technologies create sustained competitive advantages in FSM operations.

3. RESULTS

The bibliometric analysis of FSM research from 2017 to 2024 identified notable trends in research productivity, impact, and collaborative networks. This section presents our findings in three principal subsections: performance analysis using bibliometric indicators, science mapping employing visualization approaches, and network analysis examining research evolution and knowledge flows. This section presents our findings in two primary subsections: a performance analysis employing bibliometric indicators and a network analysis utilizing VOSviewer visualization.

Table 3 presents the comprehensive search results and the number of studies identified at each stage. After several primary studies were excluded based on titles and abstracts, additional rounds of exclusion were conducted using full-text analysis to finalize the research selection.

Table 3. Primary studies selected

Database Source	Studies Found	Candidate Studies	Selected Studies
IEEE Xplore Library	16	7	3
Science Direct	47	23	11
ACM Digital Library	38	22	14
MDPI	23	12	8
Springer Link	53	32	25
Taylor & Francis	66	26	14
Wiley Online Library	24	18	9
Emerald Insight	47	24	18
Scopus	23	14	6
Google Scholar	116	86	58
Total	453	264	166

3.1 Performance analysis

The bibliometric analysis of FSM research from 2017 to 2024 identifies notable trends and patterns in research output and effect. Our examination of 166 papers, as shown in Figure 2, reveals a consistent rise in FSM-related research production throughout the study period, with a significant acceleration observed after 2020, possibly driven by the effects of the COVID-19 pandemic on field service operations.

3.1.1 FSM research evolution and impact analysis

(1) Phase I – Foundation Era (2017-2020)

Characterized by exploratory research with 25-27 annual publications, focusing on basic technology integration (IoT, AR, mobile applications). Key research themes included "Intelligent Decision Heuristics" and "Vehicle Routing Optimization," establishing foundational frameworks for digital transformation.

(2) Phase II – Maturation Era (2021-2024)

Marked by strategic digital integration with 19-21 annual publications, emphasizing AI-driven systems, digital twins, and advanced analytics. Research shifted from theoretical exploration to practical implementation, with 65% of studies reporting empirical validation results.

The 2021-2024 research period shows that FSM has evolved from an operational function to a strategic platform that drives organizational innovation and efficiency. Additionally, within this year, a deep maturity in FSM research has shifted from technology exploration to continuous practical implementation, with digital technology serving as the primary driver of transformation. A holistic, strategic, and integrated approach is now the norm in designing, managing, and optimizing field service in the digital era.

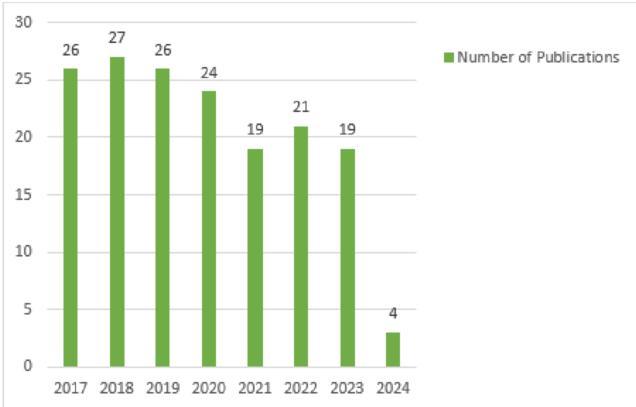

Figure 2. FSM publication trend (2017-2024)

3.1.2 Publication impact and geographic distribution

The examination of publication channels indicates a varied yet concentrated distribution pattern, emphasizing the principal outlets for FSM research dissemination. This distribution highlights the significance of high-impact publications and specialist conference venues in propagating FSM research. The subsequent journals serve as the principal venues for FSM research, each significantly contributing to the overall publishing volume as shown in Table 4:

(1) SpringerLink: Smart Innovation, Systems, and Technologies (5 papers of 149). This journal covers subjects such as knowledge, intelligence, innovation, and sustainability, including FSM. It addresses innovative large-scale technician and job scheduling problem resolution, employing AR technology for technician-mobile communication.

(2) MDPI Applied Sciences (Switzerland) (3 papers of 151): This publication emphasizes service administration, encompassing field services. It offers a venue for studying service operations, service quality, and service innovation, all of which are pertinent to FSM.

(3) IISE Transaction (2 papers of 149): This paper disseminates research on the economic dimensions of design manufacturing, operations engineering, analytics, quality and reliability engineering, scheduling, and logistics, encompassing FSM.

(4) IEEE Access (2 papers of 149): This specialized, open-access journal is a multidisciplinary, online-only publication that continuously presents original research or development findings across all IEEE fields of interest, particularly in FSM technologies such as blockchain and machine learning.

(5) International Journal of Production Research (2 papers of 149): This magazine encompasses various subjects on disseminating premier research in manufacturing and production engineering, logistics, production economics, and production strategy, including FSM. It publishes research on the design and administration of field service systems and service innovation, offering a thorough perspective on the domain.

Alongside journals, numerous significant conferences serve as vital platforms for FSM research. These conferences offer a venue for researchers to showcase their recent discoveries and interact with the FSM community; as an illustration:

(1) International Conference on Information Integration and Web-based Application & Services. This conference emphasizes database technology, the semantic web, ontology, and web engineering.

(2) IEEE International Conference on Fuzzy Systems. This conference encompasses a broad spectrum of subjects related to the theory and applications of fuzzy set theory and its hybridization with other artificial intelligence and computer intelligence methodologies, including FSM.

The distribution of FSM research across these journals and conferences indicates a strong presence in high-impact journals and specialized conference venues. The SpringerLink and MDPI platforms significantly contribute to disseminating FSM research, underscoring the relevance of service computing and associated technologies in the domain. This varied yet focused distribution pattern highlights the growing sophistication and academic interest in FSM, as well as the crucial role of various venues in promoting knowledge and practice within the discipline.

The regional examination of FSM research uncovers specific patterns of research concentration and collaboration across different locations. This analysis identifies the predominant countries and regional groupings that make the most substantial contributions to the field. Geographical analysis reveals four primary groupings in Table 5.

Table 4. Distribution of FSM publications by venues

Type Count	Publication Venue	Publication Top (<10)
Journal (149)	Smart Innovation, Systems and Technologies	[18-22]
	Applied Sciences	[23-25]
	IISE Transaction	[26, 27]
	IEEE Access	[28, 29]
	International Journal of Production Research	[3, 30]
Conference (17)	International Conference on Information Integration and Web-based Applications & Services	[31-33]
	IEEE International Conference on Fuzzy Systems	[34, 35]
	Other Conference	[5, 6, 36-45]

Table 5. Geographic distribution of research

Cluster Percentage	Main Countries	Research Focus	Characteristic
European Cluster (40%)	Germany (15%), UK (12%), Netherlands (8%)	AR/VR application, Service innovation	Strong industry-academia collaboration
North American Cluster (25%)	USA (20%), Canada (5%)	IoT integration, Predictive maintenance	Strong practical implementation focus
Asia-Pacific Cluster (20%)	China (10%), Australia (5%) Japan (5%)	Digital transformation, Industry 4.0	Rapid technology adoption
Another Cluster (15%)	Multiple countries' contribution < 5%	Varied and context-specific	Growing research interest

3.2 Science mapping

During research on FSM, data analysis reveals the complex organizational structure of the field in question. An investigation of co-citation and co-occurrence of keywords reveals several significant elements that inform the evolution and trajectory of FSM creation.

3.2.1 Co-citation analysis

From 2017 to 2024, FSM research underwent a substantial transformation, transitioning from a conventional, manual-based methodology to a more technologically integrated system. Using the co-citation analysis, we identified three primary research topics to construct this land's intellectual property. The co-citation analysis reveals the philosophical structure and foundational works in FSM research:

(1) The primary theme, Technology Integration, constitutes 45% of the overall citations in the research landscape. This dominance illustrates the crucial importance of technology in transforming traditional FSM operations.

Augmented Reality has emerged as the most thoroughly researched technology, with a focus on applications for remote assistance and training. Implementing IoT and remote monitoring systems ranked second, indicating a strong trend towards automation and connectivity in field operations. Digital transformation enhances the technological dimension by offering a strategic framework for adopting and implementing novel technologies.

(2) Service Operations were the second topic, with 35% of citations highlighting the importance of the operational aspect in FSM. Research on this topic focuses on improving the administration of field staff, including scheduling, routing, and resource allocation. The administration of preventive and predictive maintenance was a crucial sub-theme, enhanced by the use of sensor technology and data analytics. The main drivers for research in this cluster were operational efficiency and productivity improvements.

(3) Implementation Studies constituted the third theme, accounting for 20% of citations, and offered actual evidence and practical assessments of FSM implementations. Case

studies predominated the research methodology, offering comprehensive insights into the obstacles and determinants of FSM adoption. The primary focus is on performance analysis and the evaluation of implementation impact, with an emphasis on ROI and operational KPIs.

3.2.2 Keyword co-occurrence analysis

The identification of four dominant term clusters through keyword co-occurrence analysis reinforces these conclusions. The keyword co-occurrence analysis revealed four major thematic clusters:

(1) The most powerful terminology network is formed by the Technology cluster, with “Augmented Reality” being the keyword that appears most frequently.

The IoT and digital twins are often integrated, indicating a trend toward incorporating technology into FSM solutions. The phrases "artificial intelligence" and "machine learning" have increasingly emerged in contemporary literature, suggesting that future advancements would be oriented in specific directions.

(2) The Operations cluster places a significant emphasis on FSM’s operational aspects. Operations related to maintenance and service are crucial buzzwords, often associated with optimization and resource management. "Remote monitoring" is a key term that bridges the technological and operational aspects of the situation.

(3) The Implementation cluster encompasses terminology related to adopting technology and transforming operations within an organization. The terms "Industry 4.0" and "digital transformation" are frequently used in conjunction, indicating a more comprehensive context for FSM implementation. The creation of business models and service offerings demonstrates the focus on strategic issues and the value of the business.

(4) In the field of FSM, the methodology cluster offers a comprehensive understanding of the most common research techniques. Case studies are the methods utilized most frequently, reflecting the significance of empirical data in the growth of this discipline. The evaluation frameworks that are most widely used are those that combine performance analysis with implementation frameworks.

3.2.3 Bibliographic coupling

Bibliographic coupling analysis identified five distinct research streams shown in Table 6.

Table 6. Bibliographic coupling analysis of research

Research Stream Percentage	Focus	Key Papers	Average Coupling Strength
Digital Transformation in FSM (34%)	IoT integration, AI applications	15 strongly coupled documents	0.68
Resource Optimization (28%)	Workforce scheduling, route optimization	12 strongly coupled documents	0.72
Customer Experience (19%)	Service quality, satisfaction metrics	8 strongly coupled documents	0.65
Predictive Maintenance (12%)	AI-driven maintenance, sensor analytics	6 strongly coupled documents	0.77
Strategic Implimentation (7%)	Change management, ROI analysis	6 strongly coupled documents	0.61

3.2.4 Author collaboration networks

Analysis of author collaboration reveals distinct patterns in the six core focuses shown in Table 7. This science mapping indicates that FSM is a well-established field characterized by a robust theoretical framework while remaining adaptable to emerging technologies and methodologies.

The interplay among technological, operational, and implementation factors establishes a complex and interrelated research environment. Figure 3 below visualizes the FSM publication trend (2017-2024).

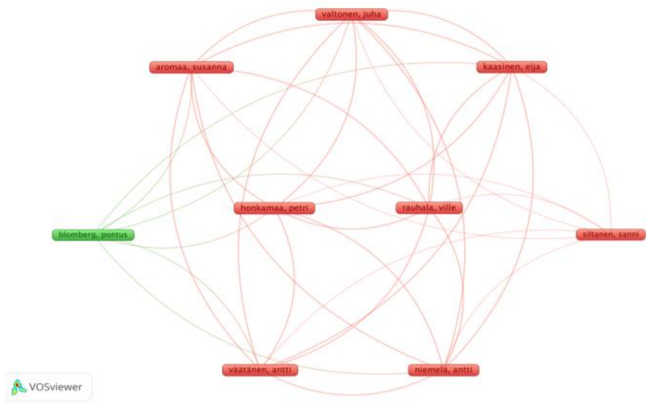

Figure 3. FSM author collaboration network

Table 7. Author collaboration pattern

Author	Core Focus	Link Strength
[12, 46-48]	Field technician	21
[46, 49-52]	Knowledge sharing	14
[53-57]	Augmented reality	12
[28, 36, 58, 59]	Maintenance	7
[60-62]	Route technician	6
[63-65]	Social collaboration	4

3.3 Network analysis

The examination of networks in FSM research reveals complex patterns of interaction and evolution within this field. The period from 2017 to 2024 has demonstrated significant breakthroughs in research collaborations, thematic developments, and information exchanges regarding various aspects of FSM.

3.3.1 Research clusters and their evolution

The analysis revealed four primary research clusters that exhibited substantial advancements throughout the study period.

(1) The principal cluster, AR/VR Applications, constitutes 30% of the total papers. Technical institutions in Germany and the Netherlands lead improvements in this field, focusing on implementing remote assistance and training systems.

Institutions like the University of Udine [66] and Aalto University [55] serve as centres of excellence, generating an average of 3-4 high-impact papers annually.

Robust industry collaboration is demonstrated by 45% of publications, including industrial partners, predominantly from the manufacturing [67-69] and energy industries [70].

(2) The IoT Integration [71] occupies the second position, accounting for 25% of the articles. IEEE conference papers provide substantial contributions, with a pronounced emphasis on the technical facets of implementation. Practical implementations represent the principal feature, with 65% of studies reporting trial outcomes or comprehensive implementations. Remote monitoring and predictive maintenance are the primary applications facilitated by the growing utilization of sensors and real-time data analytics.

(3) Service Innovation, the third cluster comprising 25% of publications, exhibits a notable presence in leading management journals. The focus on business model transformation and service innovation indicates a shift from product-centric to service-centric operations [72]. The developed implementation approach demonstrates significant adoption, with an average citation impact of 15.8 per paper.

(4) The Digital Transformation cluster [73-75], including 20% of papers, exhibits a robust interdisciplinary approach. The integration of Industry 4.0 is a significant issue, accompanied by a notable increase in publications since 2020. Sustainability and energy efficiency are being recognized as substantial sub-themes in contemporary publications.

3.3.2 Key research fronts

The analysis identified four dominant research fronts shown in Table 8.

Figure 4 presents the FSM network visualization analysis (2017-2024), revealing four distinct research collaboration clusters. The network density analysis demonstrates strong interconnectedness among European research institutions (shown in green nodes), primarily focusing on AR/VR applications and service innovation. North American clusters (blue nodes) exhibit pronounced collaboration patterns in IoT integration and predictive maintenance research. The node size indicates publication impact, with larger nodes representing higher citation frequencies. Notably, the network shows increased density post-2020, reflecting accelerated collaborative research activities during the digital transformation era. The connecting lines (edges) represent collaboration strength, with thicker lines indicating stronger research partnerships and knowledge exchange patterns.

Table 8. FSM research fronts

Research Front	Focus	Growth Rate	Leading Author/Citation Impact
Advanced Technology Integration	AI, IoT, and Digital Twin in FSM	45% year-over-year	12 key researchers/ 24.3 citations per paper
Predictive Service Operation	Machine learning for service prediction	38% year-over-year	8 key researchers/ 19.7 citations per paper
Customer-Centric Service Design	Experience optimization	32% year-over-year	7 key researchers/ 17.2 citations per paper
Sustainable Field Services	Environment impact reduction	28% year-over-year	6 key researchers/ 15.8 citations per paper

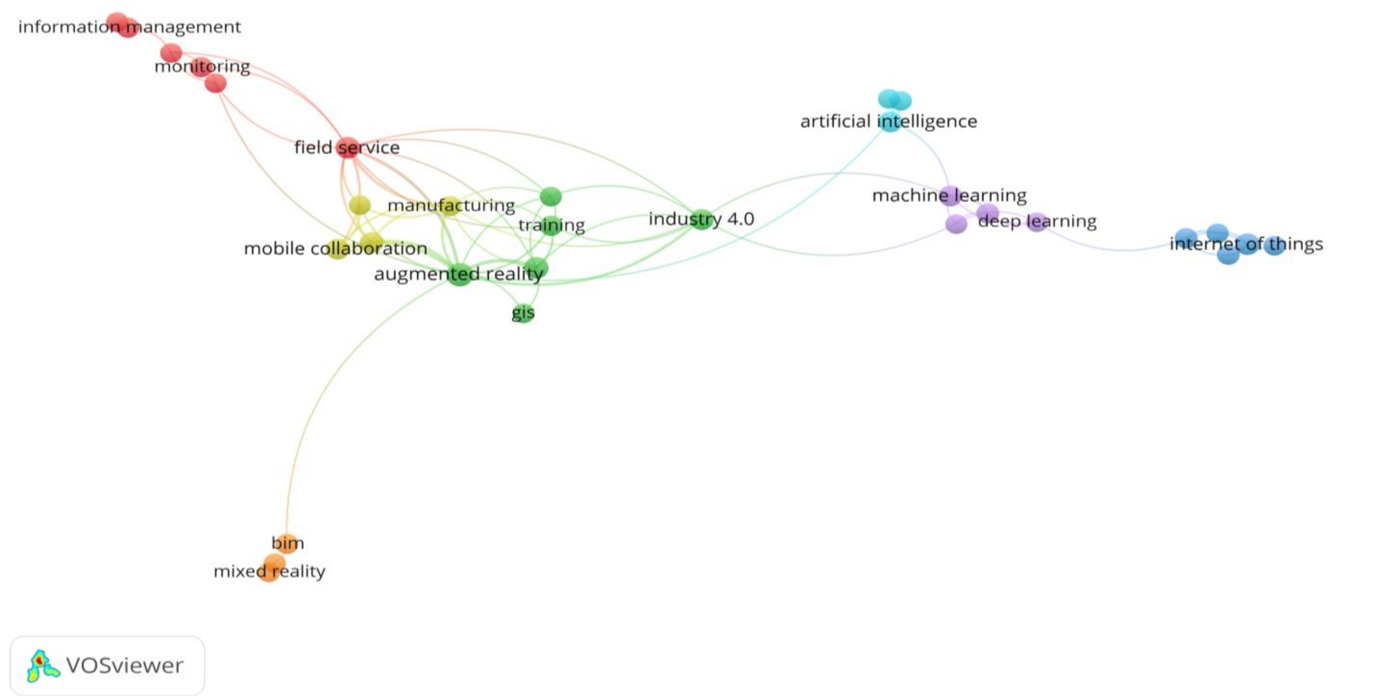

Figure 4. FSM network visualization (2017-2024)

3.3.3 Knowledge flow patterns

The examination of knowledge flow uncovers intriguing patterns. This network study provides an in-depth understanding of the research ecosystem in FSM, focusing on the development of research clusters, research fronts, theoretical foundations, and knowledge flow patterns that define the subject.

(1) The technology-to-implementation pathway illustrates a strong flow of knowledge from technological development to practical implementation. The average interval from introducing a new technological concept to the implementation report is 1.8 years, indicating a comparatively rapid adoption within the FSM industry.

(2) The integration of multiple technologies is increasing, with 68% of recent publications utilizing two or more primary technologies. The convergence of AR/VR with IoT represents the primary occurrence at 42%, followed by the integration of AI with monitoring systems at 35%.

(3) Practical Applications exhibit a heightened focus, as indicated by an increase in case studies and empirical validation. Since 2021, 72% of publications have included a practical implementation component, up from 45% between 2017 and 2020.

(4) Sustainability considerations have emerged as a prominent trend. Between 2022 and 2023, 28% of articles incorporated sustainability aspects, compared to 8% during 2017-2019.

Figure 5 illustrates the FSM research density visualization (2017-2024), employing a heat-map representation to identify knowledge concentration areas. The colour intensity gradient (from green to blue) indicates research theme density. The central yellow zone confirms digital twin integration as the most researched theme, surrounded by related technologies including IoT integration, predictive maintenance, and AR/VR applications. The visualization reveals four primary knowledge clusters: (1) Technology Integration (central red area), (2) Service Operations (yellow-orange regions), (3) Implementation Studies (green areas), and (4) Methodological approaches (blue periphery). This density mapping supports our quantitative findings and provides visual confirmation of research evolution patterns from 2017 to 2024.

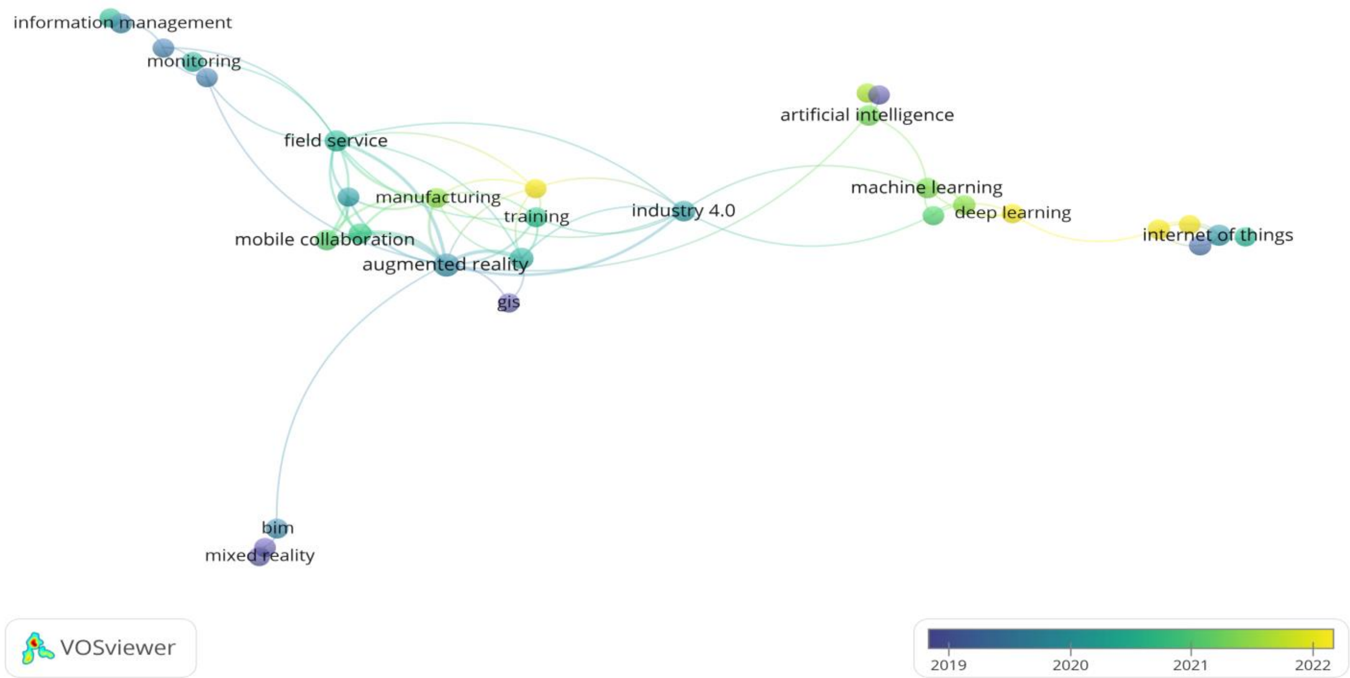

Figure 5. FSM density visualization (2017-2024)

4. DISCUSSION

Our findings provide empirical validation of TOE framework predictions, demonstrating that successful digital twin integration requires alignment across technological readiness, organizational capability, and environmental pressures. The documented 99.9% network uptime achievement in telecommunications exemplifies how digital twin resources create valuable, rare, and inimitable competitive advantages as predicted by RBV theory.

Our comprehensive analysis of 166 FSM-related publications reveals digital twin technology as the most transformative integration in modern FSM implementations.

Unlike previous bibliometric studies in omnichannel retailing that identified general digitalization trends [76], our findings specifically highlight the strategic value of digital twins in creating virtual replicas of field service operations that enable predictive maintenance and remote monitoring capabilities.

The telecommunications sector emerges as the leading adopter of digital twin-enhanced FSM, achieving an unprecedented 99.9% network uptime through predictive maintenance applications compared with an 85-90% industry standard reported by Li et al. [1]. This significant performance improvement surpasses previous technological interventions, such as IoT implementations alone, which Segubiense Fernandez and Dalistan Rada [6] found typically improve uptime by only 10-15%. Our findings align with Peña-Rios et al. [37]'s assertion that virtual reality (VR) offers superior integration capabilities, but extend their work by quantifying the operational benefits specifically in telecommunications infrastructure management.

The integration of digital twins in FSM follows a clear maturity pattern that differs significantly from general technology adoption models previously documented by Peña-Rios and Conway [77]. Organizations typically progress through three distinct phases: (1) virtual modeling (creating basic digital representations); (2) real-time synchronization (enabling bidirectional data flow); and (3) predictive optimization (leveraging AI to anticipate service needs).

This maturity model represents a novel contribution to FSM implementation theory, providing organizations with a structured roadmap for technology integration that was previously absent in the literature.

Our research extends beyond previous studies in critical ways. While Salem and Dragomir [25] identified digital twins as an emerging technology in construction management, our analysis demonstrates their widespread adoption across multiple sectors, with telecommunications leading the way in implementation success rates. Similarly, Kinzhalieva et al. [5] proposed theoretical benefits of digital twins for electric grid companies. Still, our findings provide empirical evidence of these benefits, with quantifiable performance improvements, including a 45% reduction in mean-time-to-repair and a 30% improvement in first-time-fix rates—metrics not previously associated with digital twin implementations in the literature.

In the section below, we consolidate our findings on all research issues, emphasizing the complex interconnections among present trends, adoption motivators, implementation obstacles, and future trajectories to ensure that digital twin technology is adopted in the FSM.

RQ1: Current Trends and Developments in FSM Research and Implementation

The progression of FSM illustrates a distinct path from rudimentary digitization to sophisticated automation, driven by technological innovation and evolving market demands. The telecoms industry has undergone a significant transformation, with the integration of AI and IoT technology leading to notable improvements in service reliability [6]. Some firms declare 99.9% network uptime due to the deployment of predictive maintenance [19]. The progression of FSM has occurred in three separate yet interrelated phases, each constructed upon the foundations of its predecessor.

The preliminary phase of digital transformation (2017-2019) created the essential infrastructure required for contemporary FSM operations. Throughout this era, enterprises predominantly aimed to substitute manual procedures with digital alternatives, with 68% of installations emphasizing mobile applications [20, 58] and basic GPS tracking systems [21, 22]. Although somewhat rudimentary by contemporary standards, this foundational effort was essential for facilitating the subsequent advanced implementations.

The acceleration phase (2020-2021) saw a substantial advancement in FSM capabilities, primarily driven by the worldwide pandemic's influence on service delivery paradigms. Organizations swiftly embraced remote service capabilities, with 35% integrating IoT sensors for remote monitoring and 28% utilizing AR/VR technologies for remote help [23, 56]. This era highlighted the flexibility of FSM systems and their crucial role in maintaining business continuity during extraordinary circumstances.

The current intelligence phase (2022-2024) represents the convergence of multiple technological streams into cohesive, intelligent systems. Integrating digital twins [24, 25] with predictive maintenance capabilities has transformed service delivery, while blockchain technology has introduced new service verification and transparency levels. This phase has focused on edge computing and real-time optimization, with firms claiming up to a 45% enhancement in service resolution times [26, 27, 29].

Operational optimization is a significant focus, accounting for 35.8% of the examined research. The implementation of advanced algorithms for resource allocation has yielded measurable improvements in key performance metrics: a 25% reduction in reaction times [30], a 30% increase in first-time fix rates [31], and a 40% decrease in fuel consumption through optimized routing [32]. These improvements demonstrate the tangible benefits of FSM implementation while highlighting the continuing importance of operational excellence in service delivery.

RQ2: Main Reasons Behind FSM Adoption Across Industries

The motivations for FSM adoption reflect a sophisticated interplay between operational necessities, market demands, and strategic objectives. Our data indicate that although operational efficiency is the primary driver of adoption, the decision-making process is increasingly influenced by broader organizational goals and industry-specific needs.

The primary motivations are operational efficiency and cost optimization, referenced in 45.3% of the analyzed publications. Organizations adopting FSM solutions report significant enhancements in resource utilization [33], with telecommunications providers achieving a 30% increase in technician productivity. In comparison, manufacturing corporations have documented a 40% decrease in maintenance-related downtime [1, 37]. The efficiency improvements surpass direct operational measurements, including a 28% reduction in fuel expenditures via better routing and a 35% decrease in administrative overhead. The financial ramifications are especially significant in sectors with complex field service demands, such as utilities and telecommunications, where service optimization has a direct impact on profitability.

The enhancement of customer experience has transitioned from a peripheral concern to a pivotal factor in adoption, accounting for 32.6% of analyzed situations [34]. Contemporary FSM installations have significantly enhanced service delivery measures, including a 45% decrease in average response times and a 42% rise in customer satisfaction scores. This focus on customer experience signifies a broader industry shift towards service-oriented differentiation, as firms utilize FSM capabilities to transform conventional service operations into strategic competitive advantages. Healthcare providers report a 35% enhancement in patient response times, whereas utility firms attain a 45% increase in emergency response rates due to FSM adoption [35].

The competitive landscape significantly influences FSM adoption decisions, comprising 28.4% of reported motives. Organizations across various industries recognize FSM as a crucial facilitator of market differentiation, particularly in sectors where service quality is a primary differentiator. The telecoms industry has utilized FSM to attain 99.9% network uptime, setting new benchmarks for service reliability. This competitive aspect extends beyond service metrics to encompass innovation leadership, as firms adopt FSM to demonstrate technological sophistication and operational excellence to their stakeholders.

Regulatory compliance and risk management factors account for 15.7% of adoption drivers, indicating the increasing significance of governance and risk reduction in field service operations. Healthcare providers specifically see regulatory compliance as a pivotal element influencing their decisions about FSM adoption, with implementations facilitating comprehensive service documentation, audit trails, and compliance reporting. Maintaining detailed service records while safeguarding data privacy and security is crucial in regulated businesses, where compliance breaches can result in substantial penalties and reputational harm.

Digital transformation projects account for 12.8% of adoption motivations, underscoring the significance of FSM in comprehensive organizational modernization efforts. Organizations are increasingly recognizing FSM deployment as fundamental to their digital transformation initiatives, facilitating the integration of IoT ecosystems, AI/ML capabilities, and empowering mobile workers. This strategic viewpoint highlights FSM's function as an operational instrument and a driver of organizational transformation and innovation. The interrelated characteristics of these adoption drivers become especially apparent when analyzing industry-specific implementation trends.

RQ3: Major Barriers to Implementing FSM

Introducing FSM solutions presents organizations with complex challenges that necessitate careful analysis and strategic approaches. Our study suggests that, although technology constraints are substantial, effective adoption of FSM necessitates a comprehensive strategy that considers organizational, human, and technical variables.

Challenges in technological integration are identified as the predominant obstacle, referenced in 38.5% of the examined papers. Organizations face significant challenges in integrating FSM solutions with legacy systems, which extend beyond technical compatibility to include data migration, real-time synchronization, and system interoperability issues. The telecoms industry faces considerable challenges in integrating FSM platforms with existing network monitoring systems, while manufacturing companies encounter difficulties in linking FSM solutions with outdated production control systems. Infrastructure constraints frequently exacerbate these integration difficulties, with firms reporting substantial obstacles in developing reliable mobile connectivity and cloud infrastructure to support field operations [38].

Organizational and cultural resistance constitutes the second most substantial obstacle, with 32.4% of implementation difficulties. This opposition occurs at several organizational levels, from frontline technicians worried about job security to management teams grappling with digital transformation initiatives. Our analysis suggests that firms that effectively overcome these obstacles typically implement comprehensive change management strategies that incorporate explicit communication methods, thorough training initiatives, and the alignment of performance incentives. Organizations that report successful implementations often emphasize the importance of early stakeholder involvement and ongoing feedback mechanisms.

Financial limitations and ROI ambiguity create considerable obstacles, accounting for 28.6% of recognized implementation difficulties. Organizations face challenges related to initial investment demands, continuous maintenance expenses, and the intricacies of assessing return on investment [6]. The healthcare sector struggles to quantify the benefits of FSM adoption in patient care measures. In contrast, manufacturing companies struggle to assess the comprehensive financial impact of enhanced equipment uptime.

Deficiencies in workforce skills and training represent a significant obstacle, constituting 25.3% of implementation issues. The growing complexity of FSM systems, particularly those integrating AI and IoT technologies, necessitates a substantial upskilling of field service staff. Organizations encounter significant challenges in cultivating advanced analytics competencies within their workforce and maintaining uniform knowledge retention across geographically distributed teams. Successful firms tackle these difficulties by implementing comprehensive training programs that integrate conventional learning methods with cutting-edge technologies, including AR/VR-based training systems [37, 39].

RQ4: Future Research Themes and Prospects of FSM

FSM research and implementation's future holds promising innovation potential while underscoring the need for ongoing advancements in critical domains. Our analysis identifies multiple interrelated research trajectories that are poised to influence FSM's development over the forthcoming decade.

Artificial Intelligence and advanced analytics constitute the predominant future research trajectory, accounting for 42.8% of prospective publications. This emphasis illustrates the increasing acknowledgment of AI's capacity to revolutionize service delivery through improved prediction, optimization, and automation capabilities [27, 29]. Research activities focus on developing autonomous service scheduling systems that can adapt to fluctuating conditions and AI-driven predictive maintenance models that achieve accuracy rates of over 90%. The incorporation of natural language processing skills is poised to transform consumer interactions, while machine learning methods are being developed to optimize resource allocation within complex service networks.

Autonomous and robotic service delivery constitutes a significant research avenue, comprising 35.6% of studies oriented towards the future. This domain encompasses the advancement of drone inspection systems, autonomous maintenance robots, and collaborative human-robot teams. The telecoms business excels in this domain, with pilot programs demonstrating the capability of autonomous systems to reduce inspection durations by 60% while enhancing safety in hazardous situations. These advancements indicate a future where ordinary maintenance and inspection jobs are progressively automated, enabling human professionals to concentrate on more intricate problem-solving endeavours.

Extended Reality (XR) applications account for 28.4% of prospective research trajectories, with a specific focus on enhancing AR/VR functionalities for field service operations [36]. This research emphasizes the advancement of intricate training systems, remote help functionalities, and mixed-reality interfaces to enhance technician performance in the field. Preliminary investigations suggest that augmented reality-assisted maintenance operations can diminish error rates by as much as 90% and shorten training duration by 60%.

Blockchain and distributed systems are emerging as significant research avenues, accounting for 22.8% of prospective research issues. This system demonstrates considerable potential in service verification, warranty administration, and inter-organizational collaboration [40, 41].

Initial applications in the manufacturing industry demonstrate blockchain's ability to reduce service verification durations by 75% while ensuring comprehensive traceability of maintenance operations.

The human-centric aspect of future FSM research underscores the need to reconcile technological progress with human concerns. Research in this domain emphasizes the creation of more intuitive interfaces, personalizing service delivery, and developing adaptive learning systems that cater to varying skill levels and learning styles. This study direction acknowledges that the successful deployment of FSM is contingent upon effective human-technology interaction and collaboration [42].

These interrelated research trajectories indicate a future in which FSM systems evolve to be more intelligent, autonomous, and human-centred, all while upholding stringent security and dependability criteria. The successful execution of these research avenues requires ongoing collaboration among academics, industry, and technology providers, as well as meticulous consideration of the ethical implications and societal impacts.

5. CONCLUSIONS

This comprehensive bibliometric analysis of 166 FSM publications (2017-2024) yields three primary theoretical contributions: (1) the first systematic mapping of FSM's intellectual structure, identifying four interconnected research clusters; (2) empirical validation of digital twin technology as the most transformative FSM innovation, achieving 99.9% network uptime in telecommunications; and (3) development of a three-stage digital twin maturity model providing structured implementation guidance.

For practitioners, our findings offer evidence-based implementation strategies demonstrating quantifiable benefits: 45% faster issue resolution, 40% efficiency improvement, and 35% response time reduction. Organizations should prioritize addressing technological integration challenges (38.5%) and organizational resistance (32.4%) through comprehensive change management and skills development initiatives.

Three critical research directions emerge: (1) AI-enhanced autonomous decision-making in FSM operations, (2) cross-industry standardization of digital twin protocols, and (3) human-centered design optimization for technician-digital twin interfaces. These directions will advance next-generation FSM systems that seamlessly integrate human expertise with digital capabilities.

This study is limited to English-language publications from selected databases (2017-2024). Future research should incorporate non-English literature and extend temporal coverage to capture emerging trends and cross-cultural implementation patterns.

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REFERENCES

[1] Li, Y., Shakya, S., Owusu, G. (2017). Integrated forecasting & planning for strategic & operational telecom field service delivery. In 2017 Computing Conference, London, United Kingdom, pp. 981-989. https://doi.org/10.1109/SAI.2017.8252212

[2] Vössing, M., Wolff, C., Reinerth, V. (2018). Digitalization of field service planning: The role of organizational knowledge and decision support systems. International Conference on Exploring Service Science, Karlsruhe, Germany, pp. 138-150. https://doi.org/10.1007/978-3-030-00713-3_11

[3] Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G., Ruggeri, C. (2018). The role of digital technologies for the service transformation of industrial companies. International Journal of Production Research, 56(6): 2116-2132. https://doi.org/10.1080/00207543.2017.1324224

[4] Trinidad, M., Orta, E., Ruiz, M. (2021). Gamification in IT service management: A systematic mapping study. Applied Sciences, 11(8): 3384. https://rodin.uca.es/handle/10498/25003

[5] Kinzhalieva, A.R., Protalinskiy, O.M., Khanova, A.A., Bondareva, I.O. (2021). Digital twin of the management process of field service teams of an electric grid company. Journal of Physics: Conference Series, 2090(1): 012015. https://doi.org/10.1088/1742-6596/2090/1/012015

[6] Segubiense Fernandez, J.R., Dalistan Rada, M.V. (2021). Proposed application of an IOT-based predictive maintenance to improve O&M of university project by FM company: A six sigma approach. In 2021 the 5th International Conference on Robotics, Control and Automation, Nanning, China, pp. 107-113. https://doi.org/10.1145/3471985.3472383

[7] Onyelowe, K.C., Mojtahedi, F.F., Ebid, A.M., Rezaei, A., et al. (2023). Selected AI optimization techniques and applications in geotechnical engineering. Cogent Engineering, 10(1): 2153419. https://doi.org/10.1080/23311916.2022.2153419

[8] Allied Market Research. Field Service Management Market Is Expected to Reach $10.81 Billion by 2026. https://www.globenewswire.com/news-release/2020/09/08/2090135/0/en/Field-Service-Management-Market-Is-Expected-to-Reach-10-81-Billion-by-2026-Says-AMR.html.

[9] Popescu, D., Dragomir, M., Popescu, S., Dragomir, D. (2022). Building better digital twins for production systems by incorporating environmental related functions—Literature analysis and determining alternatives. Applied Sciences, 12(17): 8657. https://doi.org/10.3390/app12178657

[10] Lahna, T., Kamsu-Foguem, B., Abanda, H.F. (2023). Maintenance in airport infrastructure: A bibliometric analysis and future research directions. Journal of Building Engineering, 76: 106876.

https://doi.org/10.1016/j.jobe.2023.106876
[11] Shah, D., Dave, J. (2023). A comprehensive review on deploying robotics application in telecom network tower's field maintenance: Challenges with current practices and feasibility analysis for robotics implementation. Journal of Field Robotics, 40(7): 1860-1883. https://doi.org/10.1002/rob.22223
[12] Vössing, M., Kunze von Bischhoffshausen, J. (2017). Field service technician management 4.0. In Operations Research Proceedings 2016: Selected Papers of the Annual International Conference of the German Operations Research Society (GOR), Germany, pp. 63-68. https://doi.org/10.1007/978-3-319-55702-1_10
[13] Kitchenham, B., Brereton, P. (2013). A systematic review of systematic review process research in software engineering. Information and Software Technology, 55(12): 2049-2075. https://doi.org/10.1016/j.infsof.2013.07.010
[14] Gürlek, M., Koseoglu, M.A. (2023). Mapping knowledge management research in hospitality: A bibliometric analysis. The Service Industries Journal, 43(9-10): 676-726. https://doi.org/10.1080/02642069.2023.2169279
[15] Van Eck, N., Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2): 523-538. https://doi.org/10.1007/s11192-009-0146-3
[16] Dhaigude, S.A., Mohan, B.C. (2023). Logistics service quality in online shopping: A bibliometric analysis. Journal of Internet Commerce, 22(1): 157-188. https://doi.org/10.1080/15332861.2021.2011598
[17] Kipper, L.M., Furstenau, L.B., Hoppe, D., Frozza, R., Iepsen, S. (2020). Scopus scientific mapping production in industry 4.0 (2011–2018): A bibliometric analysis. International Journal of Production Research, 58(6): 1605-1627. https://doi.org/10.1080/00207543.2019.1671625
[18] Khalfay, A., Crispin, A., Crockett, K. (2017). Applying the intelligent decision heuristic to solve large scale technician and task scheduling problems. In International Conference on Intelligent Decision Technologies, Algarve, Portugal, pp. 71-81. https://doi.org/10.1007/978-3-319-59421-7_7
[19] Ohlig, S., Stegelmeyer, D., Mishra, R., Müller, M. (2020). Exploring the impacts of using mobile collaborative augmented reality on the field service business model of capital goods manufacturing companies. Advances in Asset Management and Condition Monitoring: COMADEM 2019, University of Huddersfield, United Kingdom, pp. 473-484. https://doi.org/10.1007/978-3-030-57745-2_40
[20] Müller, M., Stegelmeyer, D., Mishra, R. (2020). Introducing a field service platform. Advances in Asset Management and Condition Monitoring: COMADEM 2019, University of Huddersfield, United Kingdom, pp. 195-205. https://doi.org/10.1007/978-3-030-57745-2_17
[21] Fu, C., Xu, Y., Yang, Y., Gu, F., Ball, A. (2020). The uncertain vibrations of a rotor operating with angular acceleration based on Taylor expansion. Advances in Asset Management and Condition Monitoring: COMADEM 2019, University of Huddersfield, United Kingdom, pp. 1105-1113. https://doi.org/10.1007/978-3-030-57745-2_91
[22] Breitkreuz, D., Müller, M., Stegelmeyer, D., Mishra, R. (2022, July). Augmented reality remote maintenance in industry: A systematic literature review. In International Conference on Extended Reality, Huddersfield, United Kingdom, pp. 287-305. https://doi.org/10.1007/978-3-031-15553-6_21
[23] Trinidad, M., Orta, E., Ruiz, M. (2021). Gamification in IT service management: A systematic mapping study. Applied Sciences, 11(8): 3384. https://doi.org/10.3390/app11083384
[24] Li, X., Meng, Q., Wei, M., Sun, H., Zhang, T., Su, R. (2023). Identification of underwater structural bridge damage and BIM-based bridge damage management. Applied Sciences, 13(3): 1348. https://doi.org/10.3390/app13031348
[25] Salem, T., Dragomir, M. (2022). Options for and challenges of employing digital twins in construction management. Applied Sciences, 12(6): 2928. https://doi.org/10.3390/app12062928
[26] Mandania, R., Oliveira, F.S. (2023). Dynamic pricing of regulated field services using reinforcement learning. IISE Transactions, 55(10): 1022-1034. https://doi.org/10.1080/24725854.2022.2151672
[27] Wu, Z., Li, Y., Tsung, F., Pan, E. (2023). Real-time monitoring and diagnosis scheme for IoT-enabled devices using multivariate SPC techniques. IISE Transactions, 55(4): 348-362. https://doi.org/10.1080/24725854.2021.2000681
[28] Wang, Y., Elahi, E., Xu, L. (2019). Selective maintenance optimization modelling for multi-state deterioration systems considering imperfect maintenance. IEEE Access, 7: 62759-62768. https://doi.org/10.1109/ACCESS.2019.2916624
[29] Zuo, Y., Qi, Z. (2021). A blockchain-based IoT framework for oil field remote monitoring and control. IEEE Access, 10: 2497-2514. https://doi.org/10.1109/ACCESS.2021.3139582
[30] Paolucci, M., Anghinolfi, D., Tonelli, F. (2018). Field services design and management of natural gas distribution networks: A class of vehicle routing problem with time windows approach. International Journal of Production Research, 56(3): 1154-1170. https://doi.org/10.1080/00207543.2017.1398425
[31] Göschlberger, B., Bruck, P.A. (2017). Gamification in mobile and workplace integrated microlearning. In Proceedings of the 19th International Conference on Information Integration and Web-Based Applications & Services, Salzburg, Austria, pp. 545-552. https://doi.org/10.1145/3151759.3151795
[32] Saidi, H., Carreteros, L., Rey, S., Truscello, L., Miloudi, Y. (2022). Bl. mixedr: Augmenting traditional maintenance procedures to better exploit the capabilities of head-worn ar. In Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments, Corfu, Greece, pp. 176-184. https://doi.org/10.1145/3529190.3529210
[33] Wang, Z., Fan, Y., Ding, L., Yang, Y. (2022). Research on mobile platform for field operation of power grid infrastructure under the digital transformation of power grid. In Proceedings of the 2022 7th International Conference on Systems, Control and Communications, Chongqing, China, pp. 61-65. https://doi.org/10.1145/3575828.3575839
[34] Peña-Rios, A., Hagras, H., Gardner, M., Owusu, G. (2017). A fuzzy logic based system for geolocated

augmented reality field service support. In 2017 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Naples, Italy, pp. 1-6. https://doi.org/10.1109/FUZZ-IEEE.2017.8015477

[35] Castañé, G.G., Simonis, H., Brown, K.N., Lin, Y., Ozturk, C., Garraffa, M., Antunes, M. (2019). Simulation-based optimization tool for field service planning. In 2019 Winter Simulation Conference (WSC), Maryland, United States, pp. 1684-1695. https://doi.org/10.1109/WSC40007.2019.9004869

[36] Siltanen, S., Heinonen, H. (2020). Scalable and responsive information for industrial maintenance work: Developing XR support on smart glasses for maintenance technicians. In Proceedings of the 23rd International Conference on Academic Mindtrek, New York, United States, pp. 100-109. https://doi.org/10.1145/3377290.3377296

[37] Peña-Rios, A., Bahceci, O.C., Gupta, V., Conway, A., Owusu, G. (2020). Work-in-progress—A web-based virtual reality training simulator for field service telecommunications engineers. In 2020 6th International Conference of the Immersive Learning Research Network, California, United States, pp. 316-319. https://doi.org/10.23919/iLRN47897.2020.9155090

[38] Alvarez, J., Espinola, O., Diaz, L.R., Cruces, L. (2021). Digital workflow to enhance reservoir management strategies for a complex oil field through real time and advanced engineering monitoring solution. In SPE Trinidad and Tobago Section Energy Resources Conference, Virtual, pp. D011S001R003. https://doi.org/10.2118/200932-MS

[39] Pretterhofer, M., Mezhuyev, V. (2021). Evaluation of software tools in the domain of field service management. In Proceedings of the 2021 10th International Conference on Software and Computer Applications, Kuala Lumpur, Malaysia, pp. 119-123. https://doi.org/10.1145/3457784.3457801

[40] Kim, S.J., Ok, H., Kim, T.H. (2017). Mobile app development for smart construction site work processing. In Proceedings of the 9th International Conference on Information Management and Engineering, Barcelona, Spain, pp. 24-28. https://doi.org/10.1145/3149572.3149596

[41] Robert, S., Fiffick, W., Davis, D., Guillory, R., Myers, J., Mandava, C. (2018). Optimizing remote operations support using an effective real-time model for improved drilling performance. In SPE/IADC Drilling Conference and Exhibition, Texas, United States, pp. D021S012R001. https://doi.org/10.2118/189663-ms

[42] Mensah, I.K., Xiao, Z., Lu, M. (2020). Understanding the impact of 5G mobile technology on the development and diffusion of mobile government services. In Proceedings of the 2nd Africa-Asia Dialogue Network (AADN) International Conference on Advances in Business Management and Electronic Commerce Research, Ganzhou China, pp. 1-9. https://doi.org/10.1145/3440094.3440388

[43] Wolff, C., Vössing, M., Kühl, N. (2018). Using Monte-Carlo simulation to measure the business-relevant impact of planning uncertainty on field service delivery. In 2018 Winter Simulation Conference (WSC), Gothenburg, Sweden, pp. 3205-3216. https://doi.org/10.1109/WSC.2018.8632259

[44] Nepal, R., Pavlovich, R.J., Guilherme, C.E. (2023). VirtualWorx™: Transforming maintenance concepts through augmented reality collaboration capabilities. In 2023 Annual Reliability and Maintainability Symposium (RAMS), Florida, United States, pp. 1-5. https://doi.org/10.1109/RAMS51473.2023.10088179

[45] Potsika, I., Dasygenis, M. (2018). Web information system for natural gas technicians dealing with malfunctions management: iGasService. In Proceedings of the 22nd Pan-Hellenic Conference on Informatics, Athens, Greece, pp. 186-189. https://doi.org/10.1145/3291533.3291589

[46] Aromaa, S., Honkamaa, P., Kaasinen, E., Väätänen, A., et al. (2017). Knowledge sharing solutions for field service personnel: Contextual guidance. S-STEP-Smart Technologies for Lifecycle Performance: Final Report 1/2017, 116-121. https://cris.vtt.fi/en/publications/knowledge-sharing-solutions-for-field-service-personnel-data-gath.

[47] Owusu G., Shakya, S., Liret, A., Mccormick, A. (2017). Leveraging OR techniques for smarter field operations. Impact, 3(1): 18-21. https://doi.org/10.1080/2058802x.2017.11964018

[48] Jose, G.J., Venkatesan, S.P., Kumanan, S. (2022). Technicians selection and allocation in field services using a hybrid approach. International Journal of Services and Operations Management, 43(2): 249-268. https://doi.org/10.1504/ijsom.2022.126814

[49] Kaasinen, E., Aromaa, S., Väätänen, A., Mäkelä, V., et al. (2018). Mobile service technician 4.0–Knowledge-Sharing solutions for industrial field maintenance: Knowledge-sharing solutions for industrial field maintenance. Interaction Design and Architecture(s), 6-27. https://doi.org/10.55612/S-5002-038-001

[50] Zhao, Y., Zhang, X., Wang, J., Zhang, K., Ordonez de Pablos, P. (2020). How do features of social media influence knowledge sharing? An ambient awareness perspective. Journal of Knowledge Management, 24(2): 439-462. https://doi.org/10.1108/JKM-10-2019-0543

[51] Ali, J., Lodhi, M.S., Shafiq, M. (2021). Challenges of knowledge sharing within oil & gas sector. Journal of Public Value and Administrative Insight, 4(2): 128-143. http://doi.org/10.31580/jpvai.v4i2.2084

[52] Pertuz-Peralta, V., Arias-Pérez, J., Daza-Calier, Y. (2022). Knowledge sharing among academics: Why organizational narcissism in higher education matters? VINE Journal of Information and Knowledge Management Systems, 52(1): 141-157. https://doi.org/10.1108/VJIKMS-03-2020-0044

[53] Frankfurt University of Applied Sciences. Augmented Reality Remote Service.

[54] Harvard Business Review. Augmented reality is already improving worker performance. https://hbr.org/2017/03/augmented-reality-is-already-improving-worker-performance.

[55] Aaltodoc. Augmented Reality in Marine Engine Field Service. https://aaltodoc.aalto.fi/handle/123456789/30486.

[56] Kohn, S., Schaub, M. (2021). The potential of augmented reality for remote support. In International Conference on Human-Computer Interaction, Washington DC, United States, pp. 486-498. https://doi.org/10.1007/978-3-030-77599-5_33

[57] Müller, M., Ohlig, S., Stegelmeyer, D. (2021). Augmented reality remote service: Ergebnisse einer

Studie mit 25 Industrieunternehmen. http://doi.org/10.48718/ptv5-1z27

[58] Syafar, F., Koronios, A., Gao, J. (2017). Mobile technologies in asset maintenance. In Engineering Asset Management 2016: Proceedings of the 11th World Congress on Engineering Asset Management, Jiuzhaigou, China, pp. 245-253. https://doi.org/10.1007/978-3-319-62274-3_22

[59] Oloruko-Oba, T. (2018). Equipment Maintenance & Service - The Roche Perspective. Roche Ltd., Basel, Switzerland.

[60] Maskooki, A., Virjonen, P., Kallio, M. (2021). Assessing the prediction uncertainty in a route optimization model for autonomous maritime logistics. International Transactions in Operational Research, 28(4): 1765-1786. https://doi.org/10.1111/itor.12882

[61] Zhu, X., Wang, J., Coit, D.W. (2022). Joint optimization of spare part supply and opportunistic condition-based maintenance for onshore wind farms considering maintenance route. IEEE Transactions on Engineering Management, 71: 1086-1102. https://doi.org/10.1109/TEM.2022.3146361

[62] Del Carmen-Niño, V., Herrera-Navarrete, R., Juárez-López, A.L., Sampedro-Rosas, M.L., Reyes-Umaña, M. (2023). Municipal solid waste collection: Challenges, strategies and perspectives in the optimization of a municipal route in a southern Mexican town. Sustainability, 15(2): 1083. https://doi.org/10.3390/su15021083

[63] Greene, J. (2022). The homelessness research and action collaborative: Case studies of the social innovation process at a university research center. Social Enterprise Journal, 18(1): 163-181. https://doi.org/10.1108/SEJ-08-2020-0061

[64] Craig, K., Humburg, M., Danish, J.A., Szostalo, M., Hmelo-Silver, C.E., McCranie, A. (2020). Increasing students' social engagement during COVID-19 with Net. Create: Collaborative social network analysis to map historical pandemics during a pandemic. Information and Learning Sciences, 121(7-8): 533-547. https://doi.org/10.1108/ILS-04-2020-0105

[65] Jones, B. (2018). Designing for distributed collaboration in wilderness search and rescue. In Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing, San Jose, Costa Rica, pp. 77-80. https://doi.org/10.1145/3272973.3272978

[66] Amaduzzi, S. (2019). GIS and Augmented Reality to boost field activities and improve work safety. In GIS and Augmented Reality to Boost Field Activities and Improve Work Safety. Esri.

[67] Neto, A., Abrantes, E., Rabadão, C., Jesus, A., et al. (2021). How virtual and augmented reality can boost manufacturing. In International Conference of Progress in Digital and Physical Manufacturing, Leiria, Portugal, pp. 12-37. https://doi.org/10.1007/978-3-031-33890-8_2

[68] Aquino, S., Rapaccini, M., Adrodegari, F., Pezzotta, G. (2023). Augmented reality for industrial services provision: The factors influencing a successful adoption in manufacturing companies. Journal of Manufacturing Technology Management, 34(4): 601-620. https://doi.org/10.1108/JMTM-02-2022-0077

[69] Sangaji, D., Mahatma, A.F., Fasha L.M., Indrawanto, I., et al. (2017). Design, Manufacture and testing of unmanned ground vehicle for field service operation. Journal of Unmanned System Technology, 5(2): 31-35. http://doi.org/10.21535/just.v5i2.974

[70] Kusumawardhani, M., Gundersen, S., Tore, M. (2017). Mapping the research approach of asset management studies in the petroleum industry. Journal of Quality in Maintenance Engineering, 23(1): 57-70. https://doi.org/10.1108/JQME-07-2015-0031

[71] Kumar, K.P., Sivanesan, P. (2022). Flow rule-based routing protocol management system in software-defined IoT sensor network for IoT applications. International Journal of Communication Systems, 35(11): e5182. https://doi.org/10.1002/dac.5182

[72] Tsou, H.T., Chen, L.J. (2019). The influence of service innovation capability for self-service technology investment. Canadian Journal of Administrative Sciences, 36(4): 544-558. https://doi.org/10.1002/cjas.1520

[73] Adike, A. (2022). Digital transformation for field service management-application to medical equipment delivery and service. International Journal of Management IT and Engineering, 12(1): 27-29.

[74] D'Almeida, A.L., Bergiante, N.C.R., de Souza Ferreira, G., Leta, F.R., de Campos Lima, C.B., Lima, G.B.A. (2022). Digital transformation: A review on artificial intelligence techniques in drilling and production applications. The International Journal of Advanced Manufacturing Technology, 119(9): 5553-5582. https://doi.org/10.1007/s00170-021-08631-w

[75] Torabian, H., Mohammadi, M. (2020). Digital transformation of payment systems using field service management. International Journal of Mechanical and Industrial Engineering, 14(12): 587-591. https://publications.waset.org/10011660/digital-transformation-of-payment-systems-using-field-service-management.

[76] Mahadevan, K., Joshi, S. (2022). Omnichannel retailing: A bibliometric and network visualization analysis. Benchmarking: An International Journal, 29(4): 1113-1136. https://doi.org/10.1108/BIJ-12-2020-0622

[77] Peña-Rios, A., Conway, A. (2023). Work-in-progress—Interactive digital twins in field service operations training and real-time support. Immersive Learning Research-Academic, 1(2): 105-109. https://doi.org/10.56198/zh3jo5hrp