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Review

A Bibliometric and Systematic Review of Manufacturing-as-a-Service: Literature Insights, Challenges, and Future Trends

Anastasia Karamanli [1,*], Alexandros Xanthopoulos [1], Antonios Gasteratos [1] and Dimitrios Koulouriotis [2,*]

[1] Department of Production and Management Engineering, School of Engineering, Democritus University of Thrace, V. Sofias 12, 67100 Xanthi, Greece; axanthop@pme.duth.gr (A.X.); agaster@pme.duth.gr (A.G.)
[2] School of Mechanical Engineering, National Technical University of Athens, Heroon Polytechniou 9, 15772 Athens, Greece
* Correspondence: ankarama@pme.duth.gr (A.K.); dkoulouriotis@mail.ntua.gr (D.K.)

Abstract: Manufacturing-as-a-service consists of an Industry 4.0 innovation and has been a focal point of research and business attention in recent years. MaaS provides a matching connection between manufacturing resources or capabilities as service and organizations that need to utilize them, via a digital thread. Through this approach, not all companies have to invest in heavy capital, which allows them to focus on other critical capacities. This review provides bibliometric insights, such as quantitative results regarding the annual trends, dominant publications, journals, institutions, and VOS-viewer-software-extracted networks that highlight co-occurrence of keywords and journal co-citations. Moreover, the publications are presented concisely and are critically evaluated and categorized in pilar categories based on their core concept. The current limitations and future trends in the MaaS field are identified as well. Even though it is an established, important Industry 4.0 innovation, the available literature may not provide such a holistic, comprehensive overview of MaaS. The current study not only presents critical observations of contemporary and distinguished scientific papers but also guides researchers in a systematic examination of MaaS theoretically, architecturally represented, or regarding its data-driven opportunities.

Keywords: manufacturing-as-a-service; smart manufacturing; Industry 4.0; cloud manufacturing; literature review; bibliometric analysis

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1. Introduction

This literature review presents an enriched extension of our previous work: "Manufacturing-as-a-Service: A Systematic Review of the Literature" [1]. By integrating 37 additional publications in our literature under investigation derived from the Scopus database and extracting more insights, the role of MaaS is examined from a more comprehensive perspective. Manufacturing-as-a-service [2] is a pioneering technique to the manufacturing sector that is redefining the conventional manufacturing landscape. Due to the advent of digital technologies [3–6] and the integration of the Internet of Things [7], MaaS consists of a new framework which provides on-demand manufacturing services to enterprises and individuals [8]. In this mechanism, manufacturing processes, machinery, and expertise become accessible through a service-based platform [9–11], giving the opportunity to customers to access manufacturing resources, saving them heavy capital investments or extensive infrastructure [12,13]. MaaS evolves customization [14,15], rapid prototyping [16–18], and decentralized manufacturing [19], enabling companies to streamline their supply chains [20–22], speed up time to market, and meet the changing demands of the contemporary market [23,24].

In addition, MaaS integrates sustainability in the traditional industrial landscape, by strengthening regional economies, instead of mass production and long-distance transportation [25]. Technological development puts the spotlight [26] on the efficiency of industries by embedding digitalization [27], automation, robotics, or cyber–physical systems [28] in their operation. Moreover, the utilization of edge and cloud computing [29,30] increases the profitability of the manufacturing sector with the facility of cloud manufacturing platforms [31,32]. Purchasing with online bidding, progress update, or optimized delivery [33] are only some of the advancements MaaS offers to improve customers' satisfaction.

This research presents a bibliometric report and literature review on MaaS, utilizing mathematical and statistical tools to analyze scholarly publications [34]. It provides a starting point for understanding MaaS evolution and its current state. Section 2 outlines the data sources and methods, while Section 3 presents statistical insights, including annual trends, key institutions, top journals, citation distribution, and highly cited papers. Additionally, keyword and co-citation analyses are included. Section 4 categorizes selected publications into three areas: MaaS theoretical approach, architectures, and data innovations. Section 5 summarizes findings and suggests future directions, while Section 6 discusses current limitations and emerging trends in MaaS.

This research serves as a comprehensive guide for both researchers and industry professionals, offering a structured overview of MaaS literature. By analyzing statistical data, keyword networks, and key findings from publications, it provides a clear, aggregated view of the existing research landscape, encouraging further exploration and innovation.

Key focal points of this study include the following:

- What are the primary technologies enabling MaaS?—Exploring cloud computing, IoT, blockchain, and AI in MaaS implementation.
- What are the biggest challenges to MaaS adoption?—Addressing issues such as data security, interoperability, and regulatory constraints.
- Which industries are leading in MaaS implementation?—Highlighting case studies from manufacturing, healthcare, and automotive sectors.
- What are the emerging trends in MaaS?—Identifying advancements in automation, sustainability, and decentralized production models.
- How can businesses maximize the benefits of MaaS?—Providing actionable insights into cost reduction, supply chain efficiency, and service optimization.

A bibliometric analysis was chosen as the most suitable approach, using quantitative techniques to assess research patterns and impact. By examining publication metrics, co-citation networks, and keyword co-occurrence, this review provides a clear understanding of MaaS's evolution and current state. This method highlights key contributions, influential journals, and research gaps, offering a structured, data-driven framework to unify fragmented literature and guide future investigations.

Several previous literature reviews have explored different aspects of manufacturing-as-a-service (MaaS). For example, Moghaddam et al. [24] examined the transition from service-oriented architecture to cloud manufacturing, while Tedaldi and Miragliotta [13] analyzed early adopters and deployment models of MaaS. Additionally, Barbhuiya et al. [14] introduced the SmartMaaS framework, focusing on the role of digital platforms in manufacturing ecosystems. However, unlike these studies, our review takes a bibliometric and systematic approach, integrating quantitative analysis of research trends, keyword networks, and citation patterns. This allows us to not only map the evolution of MaaS research but also identify gaps and future directions, providing a more comprehensive and data-driven perspective on the field.

2. Methods

The documents that were taken into consideration in this review were collected from the Scopus database, a universally renowned source for scholarly bibliography. Scopus consists of an extensive amount of scientifically reliable and impactful publications and provides enriched information such as citation statics, etc. Scopus was selected for its comprehensive coverage of high-impact, peer-reviewed research and robust bibliometric tools, ensuring data reliability. While some studies from other databases may be excluded, Scopus provides strong quality control and citation tracking, making it ideal for analyzing MaaS research trends.

To ensure an unbiased and meaningful selection, the following inclusion criteria were applied:

- Relevance to MaaS: Only publications directly focusing on manufacturing-as-a-service (MaaS) were considered, identified through titles, abstracts, and keywords.
- Peer-reviewed sources: Preference was given to scientifically reliable, peer-reviewed papers with strong methodologies, empirical findings, or theoretical contributions.
- Renowned academic institutions: Publications originating from established research centers and universities were prioritized.
- Database source: The Scopus database was selected for its comprehensive and high-quality scholarly coverage.
- Time frame: The search covered the last 20 years to ensure an updated and relevant dataset.
- Language criterion: Only English-language publications were included to maintain consistency and accessibility.
- Document types: The final selection consisted of proceedings papers (42 papers, 52%)—the most dominant category; journal articles (37 papers, 46%)—providing in-depth analyses; and letters (2 papers, 2%)—offering concise contributions.

This filtering process ensures a rigorous and impartial selection, maintaining a clear focus on MaaS research while enabling a systematic and data-driven literature review.

The thematic categorization of the selected publications was based on a comprehensive review of the literature, ensuring a structured and meaningful classification. The three categories, "MaaS Theoretical Approach", "MaaS Architectures", and "Data Innovations", were chosen based on recurring research themes and the core contributions of each study. Previous literature reviews have primarily focused on conceptual frameworks, technological implementations, and data-driven advancements in MaaS. This classification allows for a clear differentiation between foundational theories, system architectures, and data-centric innovations, ensuring a systematic and comprehensive analysis of the field. By adopting this approach, we aim to highlight the evolution of MaaS research, facilitating a deeper understanding of its principles, technological enablers, and future potential.

Disciplinary mapping plays a significant role in bibliometrics, offering knowledge relevant to the evolution of science. There are plenty of software tools accessible for bibliometric analysis, such as VOSviewer (version 1.6.20), CiteSpace, and GraphPad Prism. In this current review, VOSviewer [34] was utilized due to its user-friendly GUI and elevated capabilities related to co-occurrence and co-citation analysis, among others. VOSviewer was used to compose co-citation and keyword co-occurrence networks.

Compared now to other available tools, VOSviewer was used due to convenience of its specialized capabilities and conformity with the objectives of this research. This tool provides excellent visually intuitive and detailed bibliometric maps, which are essential to generate co-occurrence and co-citation patterns. Since VOSviewer manages extended datasheets effectively, its accuracy in the representation of complex bibliometric connections is proven, making it a preferred tool for exploring keyword trends and author synergies.

In comparison with CiteSpace, a proper application for temporal analysis, VOSviewer provides a more efficient, user-friendly interface with which users are easily familiarized and can immediately extract useful data. GraphPad Prism is indicated for statistical measurements and graphical representations; however, it lacks capabilities needed for the creation of bibliometric mapping. For all these reasons, VOSviewer was the most suitable tool for the objectives of the presented literature review.

3. Results

3.1. Annual Trends in MaaS and Top Institutions with Related Publications

The number of publications for recent years is presented in Figure 1a. The first MaaS-related papers were published in 2012 [35–37], and for the following 10 years, research was developed at a relatively steady pace. An increased appearance of field-related publications in the literature is observed especially after 2020. This rising direction could be attributed, among others, to the general emergence of servitization in the universal business community.

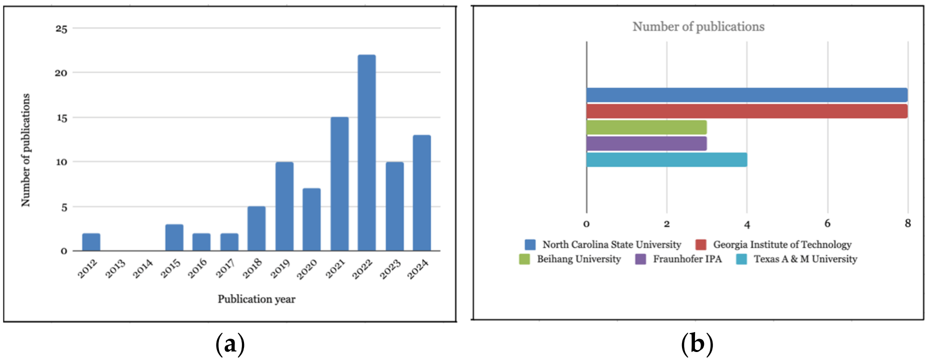
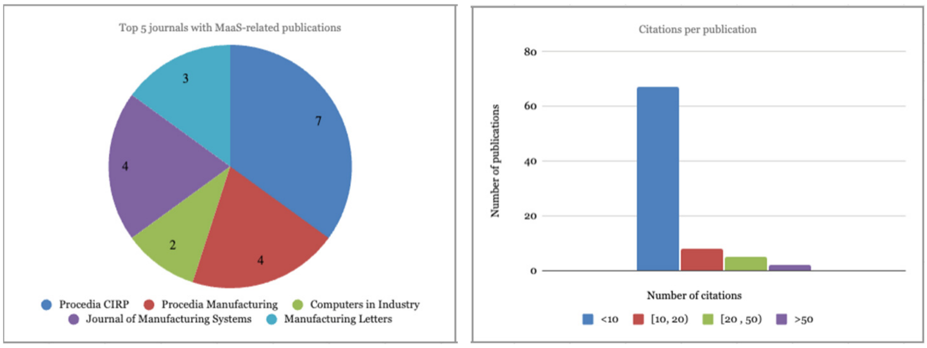


Figure 1. (**a**) Annual trends in MaaS-related publications; (**b**) the top five institutions with MaaS-related publications.

Figure 1b displays the top five institutions that have engaged in MaaS-related research; the North Carolina State University [2,7,9,38–42] and the Georgia Institute of Technology [41,43–49] have the most publications in this subject, with a total of eight papers each, accounting for approximate 10% each of all publications in this category. The two institutions are followed by Texas A & M University and finally Beihang University and the Fraunhofer IPA. Overall, the papers that were reviewed in the current research were provided by more than 40 institutions; more than 80% of the participating organizations had no more than one publication. The dominance of institutions such as North Carolina State University and Georgia Institute of Technology in MaaS research reflects their strong focus on digital manufacturing, cloud-based production, and smart manufacturing innovations. This concentration suggests that future research could benefit from broader geographical and institutional participation to diversify perspectives, enhance collaboration, and address region-specific MaaS implementation challenges.

3.2. Distribution of Sources and Citation Analysis

The 81 publications of the present study were published in more than 20 sources, among which were journals and conference proceedings. Approximately, 80% of the investigated research platforms released only one publication on MaaS. In Figure 2a are shown the five journals that circulated the most MaaS-related papers; the figure includes two headings that publish conference papers (Procedia CIRP and Procedia Manufacturing) and one heading that publishes letters. The journal which occupies the first position with the most publications is Procedia CIRP.



(**a**) (**b**)

Figure 2. (**a**) Top five journals with MaaS-related publications; (**b**) distribution of citations per publication.

Now, for the citations of the publications selected for this bibliometric analysis, they obtained a total of 712 citations; on average, each publication is cited circa nine times. Nevertheless, in Figure 2b, it is evident that the distribution of citations per paper is unbalanced, while most of the papers preserve less than ten citations. This lies in the fact that MaaS is a contemporary concept, and most publications were published not long ago. The top cited papers are shown in Table 1 [2,19,30,37,50].

Table 1. Top highly cited papers related to MaaS.

Paper Title	Source	Author Names	Publication Year	Citations
New IT driven service-oriented smart manufacturing: Framework and characteristics [50]	IEEE Transactions on Systems, Man, and Cybernetics: Systems	Tao, F., Qi, Q.	2019	344
Decentralized cloud manufacturing-as-a-service (CMaaS) platform architecture with configurable digital assets [2]	Journal of Manufacturing Systems	Hasan, M., Starly, B.	2020	93
Scheduling of manufacturers based on chaos optimization algorithm in cloud manufacturing [19]	Robotics and Computer Integrated Manufacturing	Hu, Y., Zhu, F., Zhang, L., Lui, Y., Wang, Z.	2019	70
Optimal pricing strategies for manufacturing-as-a-service platforms to ensure business sustainability [23]	International Journal of Production Economics	Chaudhuri, A., Datta, P.P., Fernandes, K.J., Xiong, Y.	2021	34
Blockchain cloud manufacturing: Shop floor and machine level [30]	Smart SysTech 2018-European Conference on Smart Objects, Systems and Technologies	Barenji, A.V., Li, Z., Wang, W.M.	2018	34

3.3. Keyword Analysis and Focal Points of MaaS Research

The co-occurrence of keywords consists of a dependable indicator of the present areas of interest in a scholarly field, such MaaS. In the 81 MaaS-relevant publications investigated in this study, a total of 836 keywords were distinguished. About 3.5% of the index terms have at least five occurrences in the examined array of publications.

For the purposes of this research, VOSviewer software (1.6.20) was utilized to generate the keyword co-occurrence network (refer to Figure 3). Each of the nodes has a different size which represents the weight assigned to them; larger nodes signify higher weights. Now, the distance between two nodes indicates the strength of their connection; shorter distances signify stronger connections. A linking line between two keywords demonstrates their co-occurrence, with thicker lines revealing a higher frequency of co-occurrence. According to their colors, the nodes belong to specific clusters; in the presented network, three clusters of keywords are detected. The index terms "manufacture" and "cloud manufacturing" have the most remarkable frequencies.

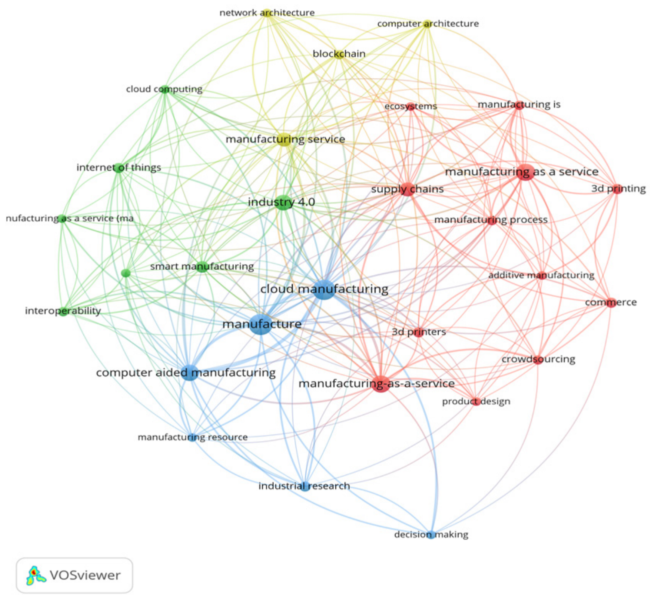


Figure 3. Keywords co-occurrence network of MaaS-related literature.

3.4. Analysis of Journal Co-Citations

To comprehend the framework and the aspects of the fundamental field, an analysis of the co-citations among journals serves as an effective method. A review of the individual source titles is provided as well. By utilizing VOSviewer software, the following co-citation network (refer to Figure 4) was extracted. The size of the node indicates the activity level of the journal, considering the number of published papers. A smaller instance between the nodes represents a higher frequency of citations. The three used colors indicate three distinct journal clusters.

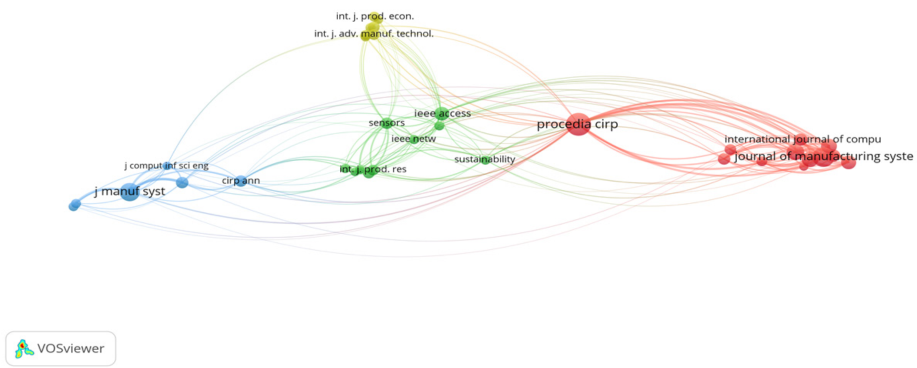


Figure 4. Journal co-citation network of MaaS-related literature.

The keyword co-occurrence network points out key investigation concepts in MaaS, such as digital transformation, cloud manufacturing, and Industry 4.0, with the main interest on expandability and resource-optimized utilization. Regarding the co-citation network, it highlights impactful journals and concepts, pointing out gaps in decision-making models, trust mechanisms, and integration strategies. These outcomes propose topics for future research to further validate MaaS integration in manufacturing.

3.5. Linking Bibliometric Findings to the Evolution of MaaS

The bibliometric findings suggest that MaaS research has followed a structured evolution:

1. Conceptual Foundation (2012–2016): Initial papers focused on defining MaaS and its connection with cloud manufacturing, servitization, and Industry 4.0 concepts.
2. Technological Advancements (2017–2020): Research started investigating blockchain integration, digital marketplaces, and decentralized manufacturing platforms, leading to high-impact studies.
3. Application and Optimization (2021–Present): Recent studies prioritize real-world case studies, machine learning applications, and supply chain optimization strategies to support MaaS implementation.

This development aligns with publication trends, revealing a shift from theoretical studies to industry-driven applications. The post-2020 surge in research reflects MaaS's technological maturity and growing business adoption. The keyword and co-citation analyses further highlight this evolution, emphasizing its expanding interdisciplinary nature. Future research should refine trust mechanisms, pricing models, and large-scale adoption strategies to accelerate MaaS integration across industries.

4. Literature Review

By investigating the publications more thoroughly, their substantial contribution to the manufacturing landscape is revealed [51]. MaaS' main goal is to automatically pair requests and applicable manufacturing capabilities through algorithms [12]. Current industries do not always fulfill the standards to easily integrate frameworks like MaaS in their operations. To overcome the current challenges, each of the selected publications for this review contributes in either a theoretical or a functional way. Therefore, the papers can be classified into three main categories, based on their content: "MaaS theoretical approach", "MaaS architectures", and "Data innovations". For instance, Kusiak [52] presents the six enablers which will strengthen universal manufacturing, providing flexibility and affinity. In this context, by establishing modern industrial strategies, such as digitization or open manufacturing, the production needs regardless of type and complexity will be covered, ensuring companies an optimization, free from boundaries concerning the market, natural or human-caused failures, and the environment. Publications that discuss the manufacturing-as-a-service subject from a theoretical and conceptual view are mentioned in Table 2, arranged in specific thematic sections.

At the same time, a significant part of the documents researched proposes a specific mechanism to preserve trust [7] and immediacy [9] between the different stakeholders of a manufacturing digital thread, which is formed thanks to the servitization [42,53] of MaaS. For example, Pahwa, Starly, and Gohen [10] recommend that final consumers name their own prices, and the mechanism designed by them tracks down service providers willing to assume the production of the part under the declared price. Brodsky et al. [54] upgrade the concept of customization by providing the ability of parameterized, composed, and optimized products. Publications which suggest a unique, designed mechanism for the unhindered integration of MaaS in the manufacturing sector are listed in Table 3, divided into particularly important categories.

Most of the collected papers, however, concentrate on the provision of data management data solutions required for the digitization and democratization [55] MaaS includes. Hasan and Starly [2] focus on the advancement of such software architecture, which connects customers with manufacturing-service providers directly, securing data transparency, integrity, origin, and ownership to creators. Documents relevant to data management solutions are listed in Table 4 below and even separated into targeted thematic modules.

Theoretical approaches, architectures, and data innovations in MaaS are inherently interconnected, forming a cohesive framework for its development and implementation. Theoretical foundations define key principles and service models, guiding the design of architectures that enable scalable and interoperable MaaS platforms. These architectures, in turn, rely on data innovations to enhance decision-making, optimize resource allocation, and ensure secure transactions. Together, these categories create a dynamic ecosystem where conceptual models inform structural frameworks, which are further refined through data-driven advancements, ensuring efficient and adaptive MaaS solutions.

Concerning the methodologies involved in the investigated publications, many of them suggest a technical approach for the integration of MaaS in modern industries. More specifically, an approach may illustrate the structure of a production flow and the data allocation [56] passing stakeholders until the final customer and are designed with the assistance of computer-aided programs [57]. Other mechanisms recommend a decision management system [43], which utilizes available data to simplify the procedures of MaaS in organizations. Through the simulation of a marketplace, Pahwa, Starly, and Gohen [9] evaluate the impact of various variables, such as pricing. Correspondingly, Tessaro, Vick, and Krüger [35] performed simulations and experiments in the laboratory to examine an on-demand service system in terms of stability, readiness, etc. Moreover, other methodologies among the papers include the formulation of a statistical model [16], solution of objective functions [44], and optimization algorithms [19,58].

The reviewed literature aligns with the overarching objectives of MaaS by emphasizing digital transformation, resource optimization, and decentralized production, yet certain aspects diverge in their scope and implementation. For instance, Wang [55] highlights the significance of data collection and processing by installing sensors in manufacturing machines, reinforcing MaaS's goal of data-driven decision-making. Similarly, blockchain architectures [38] and cloud manufacturing solutions [19,20,59] support transparency and interoperability, which are essential for MaaS adoption. Case studies further validate MaaS applications, such as Tedaldi and Miragliotta [20], who examined six different manufacturing platforms, and Liu, Gong, and Jiao [44], who implemented a low-carbon product-family-planning model in a custom kitchen construction company. While these studies contribute to key MaaS principles, some diverge by focusing on specialized applications rather than holistic MaaS integration. For example, while blockchain and cloud computing enhance security and scalability, challenges like SME adoption and regulatory compliance remain underexplored. These findings indicate that while MaaS research largely aligns with its core objectives, gaps persist in achieving full-scale, industry-wide implementation.

Regarding the practical MaaS implementation, it is proven by case studies from multiple industries, for example, the automotive sector. MaaS gave the manufacturers the opportunity to utilize decentralized production systems, which reduce lead times and costs through on-demand part production. A similar example of the healthcare sector, MaaS has empowered the rapid prototyping and production of medical devices, a useful contribution especially during periods of high demand, such as the COVID-19 pandemic. The mentioned paradigms validate the transformative perspective of MaaS across various segments, proving its role in improving efficiency and adjustability while minimizing the need for heavy capital investments.

The literature under examination reveals both alignment and divergence across different studies, highlighting key trends, contradictions, and unresolved challenges. While Hasan and Starly [2] and Barenji et al. [38] emphasize blockchain-based architectures to enhance security and trust in MaaS platforms, other studies, such as Rauschecker and Stöhr [37], prioritize interoperability without focusing on data security concerns. Similarly, Liu et al. [44] explore MaaS from a sustainability perspective, advocating for low-carbon product family planning, whereas Tedaldi and Miragliotta [20] focus on engineering-to-order business models, revealing a gap in standardized implementation strategies. Additionally, while Wang [55] and Ordienes-Meré [60] stress the importance of real-time data collection for smart manufacturing, Moghaddam et al. [24] and Hu et al. [19] highlight the need for dynamic scheduling and optimization, exposing a lack of integrated frameworks to balance flexibility with efficiency. Furthermore, the role of AI in MaaS is widely discussed, with Gong et al. [48] exploring crowdsourced manufacturing, yet challenges remain in ensuring scalability and demand forecasting [49]. These variations in focus and methodologies indicate an evolving MaaS landscape, underscoring the need for further research in trust mechanisms, SME adoption, cost-effectiveness, and large-scale interoperability.

Table 2. MaaS theoretical approach.

Core Subjects	References	Critical Features
Fundamental Theories and Concepts	[8,12,17,26,36,52,53,61]	Core MaaS enablers and theoretical concepts are defined, but industry-wide empirical validation could be farther provided
Business Models and SME Adoption	[10,51,62]	Business models, B2B platforms, and SME adoption challenges are explored, but scalability remains mostly unaddressed
Additive and Smart Manufacturing Integration	[17,26,36,51,63,64]	Examines additive and smart manufacturing but lacks large-scale supply chain integration insights
Digital Ecosystems and Servitization	[10,12,26,53,61,65]	Analyzes servitization and digital ecosystems for MaaS, though real-world applicability is limited
Industry 4.0 Enabling Technologies	[26,36,51,52,62,63,66–69]	Details Industry 4.0 technologies but highlights interoperability as a persistent challenge
Performance Metrics and Decision Support Systems	[51,61,63,64]	Presents decision support models and KPIs but lacks multi-sector validation

Table 3. MaaS architectures.

Core Subjects	References	Critical Features
Security and Trust Mechanisms	[7,9,11,14,15,22,23,25,39,40,42,43,70]	Proposes blockchain and security mechanisms but lacks broad industrial adoption data
Manufacturing Marketplaces and Pricing Models	[9,23,27,33,40,42,45,47]	Introduces dynamic pricing models but requires more real-world validation
Cloud-Based and Distributed Manufacturing	[11,23,27,31,33,39,42,45]	Explores cloud and decentralized MaaS platforms, yet interoperability challenges remain
Customization and Agile Production	[15,23,25,27,33,40,42,47]	Analyzes customization in agile manufacturing but needs validation for large-scale production
Supply Chain Optimization and Interoperability	[27,31,33,39,40,42,45]	Proposes optimization frameworks for supply chains, but regulatory barriers remain unaddressed
AI and Machine Learning in MaaS	[40,42,45,47,56,71]	Investigates AI for manufacturing automation, though real-world integration remains underexplored

Table 4. Data innovations.

Core Subjects	References	Critical Features
Blockchain and Data Security	[2,13,18,21,24,28,30,32,35,41,46,55,60,72–74]	Enhances MaaS data security using blockchain, but economic feasibility remains unassessed
Cloud and Edge Computing in MaaS	[19,24,28–30,32,35,37,38,41,46]	Cloud and edge computing support real-time decision-making, though multi-cloud integration challenges persist
AI-Driven Optimization and Decision-Making	[49,55,57,59,60,72,73,75,76]	AI models improve efficiency but need real-world validation across industries
Cybersecurity and Fault Tolerance	[29,30,32,35,37,38,41,46,49]	Cybersecurity solutions address fault tolerance but require industry-specific case studies
IIoT and Smart Manufacturing Analytics	[55,57,59,60,72,73,75]	IIoT strengthens data-driven manufacturing, though integration with legacy systems presents challenges
Data-Driven Supply Chain Management	[20,24,28–30,32,35,37,38]	Optimizes supply chain decisions but lacks standardized implementation frameworks

5. Current Limitations and Future Trends

Although, as proven in this review, substantial progress has been made toward developing production processes, specifically in MaaS implementation, there are still some limitations at this state and therefore plenty of developments yet to be met. It is often observed that executives lack decision-making capacity [64], and as a result, they must meet decisions based on immediate benefits rather than sustainable and holistic outcomes [64]. To provide efficacy and sustainability in decision-making by the managers, modeling is useful to simulate scenarios, predict participation levels and design mechanisms [47]. The majority of the MaaS systems proposed could be evolved further by taking more parameters into consideration, such as demand forecast, seasonal variation, or raw material pricing [40]. Of course, to arise a better understanding of the MaaS implication, its involved parts, the associated risks and the obtainable benefits, more MaaS platforms need to be examined to achieve a profitable comparison [77], and more information needs to be selected from industrial practitioners, for example, through questionnaires or interviews [62].

The managerial implications of MaaS affect strategic decision-making, cost optimization, and market adaptability [13,23]. Managers must use predictive analytics to improve supply chain resilience [48], while SME adoption barriers, such as digital infrastructure limitations, require policy interventions and workforce training [10]. Academically, further research on scalability, dynamic pricing, and real-world applications is essential to bridge theory with practice [2,14], ensuring holistic MaaS integration.

The current limitations in MaaS adoption, such as inadequate decision-making capacity and trust issues, significantly hinder its scalability and industry-wide implementation. For instance, Wang [55] and Ordienes-Meré [60] highlight that real-time data collection and transparency are crucial for smart manufacturing, yet many enterprises struggle with integrating secure decision-support systems, leading to inefficiencies and reduced adoption rates. Similarly, Hasan and Starly [2] and Barenji et al. [38] emphasize blockchain-based trust mechanisms as potential solutions, but concerns about implementation costs and interoperability with existing infrastructures remain key obstacles to widespread MaaS adoption.

In addition, despite the great improvements MaaS offers, its integration into small- and medium-sized enterprises (SMEs) presents important challenges. Limited or zero access to advanced digital infrastructure, lack of technical expertise, and concerns related to data protection, or trust, may hinder adoption. Moreover, MaaS mainly addresses collaborative and complex industrial frameworks, which are difficult for SMEs to align with. In order to overcome these challenges, strategical policy measures are required: assistance for digital transformation, training to upskill the employees, and the design of safe, user-friendly platforms based on the needs of SMEs. These actions are necessary for MaaS to become accessible and beneficial to smaller organizations.

Overall, the vision Industry 4.0 represents consists of achieving a more efficient and accessible personalized production process [65], which will be supported by cyber–physical systems [78], cloud manufacturing [79,80], deep learning methods [61], or machine-learning-based feature extraction methods [81]. Additionally, the more MaaS is integrated into the reality of the industries, the more technical developments will also emerge in the future. Virtual reality assists digitalization by providing the capability of off-site operation of the machinery by the employees [82]. The lack of trust in the protection of the data in all the technologies consists of one of the most crucial challenges of the contemporary manufacturing methods [41], and to be encountered, there should be integrated evidence-based and transparency-based trust mechanisms that utilize IoT and blockchain technologies as well [83].

The MaaS ecosystem introduced by Schöppenthau et al. [84] could be further developed with the addition of capabilities such as process derivation service or a search engine combined with its supplier knowledge base and an assisting software. Task-service-matching optimization problems could be enriched with the capability of the negotiation in the pricing procedure in the future [85]. As Gong et al. [48] suggest, crowdsourcing task derivation could be even more useful, by involving planning of the material flows, or mixing tasks on the shop floor in real-time. Regarding now MaaS supply chains, the challenges currently encountered include larger data volumes, node counts [86], and a complexity of managing a distributed and decentralized system [87]. To achieve a truly efficient MaaS supply chain transparency in the future, Qiao P. [86] suggests that the classification of stored data should be conducted by employing specific encrypting methods for private data.

While previous reviews have primarily focused on specific aspects of MaaS, such as its conceptual foundations [24], early adoption models [13], and framework architectures [14], this study provides a comprehensive bibliometric and systematic review, offering quantitative insights into research trends, citation patterns, and keyword networks. Unlike prior works that analyze MaaS through case studies or theoretical models [2,19], our study integrates statistical methods to identify research gaps, key influencing factors, and emerging themes. Additionally, by categorizing MaaS research into theoretical, architectural, and data-driven innovations, this review structures the fragmented literature, allowing for a more holistic understanding of the field [37]. These contributions position this study as a valuable reference point for both academics and industry practitioners, guiding future research and MaaS implementation strategies.

Future MaaS research should explore new theoretical frameworks that integrate system-of-systems theory, digital ecosystems, and servitization models to enhance scalability and interoperability. Methodologically, adopting hybrid approaches—combining bibliometric analysis with machine learning—can improve trend forecasting and research gap identification. Additionally, longitudinal case studies and experimental simulations can provide empirical validation, strengthening the theoretical foundation of MaaS in Industry 4.0. These approaches will ensure a more comprehensive understanding of MaaS evolution and its impact across industries.

Bibliometric trends reveal key research gaps, influential contributors, and emerging topics, helping funders and policymakers prioritize underexplored areas like MaaS security and AI-driven optimization. Identifying leading institutions and collaborations can also drive strategic partnerships and accelerate innovation.

6. Conclusions and Indicative Extensions

6.1. Conclusions

This study provides a bibliometric and systematic review of manufacturing-as-a-service (MaaS), analyzing research trends, technological enablers, and adoption challenges. Key findings include the following:

- Mapping the research landscape—highlighting annual trends, key contributors, and the interdisciplinary nature of MaaS research.
- Identifying technological enablers—such as cloud computing, blockchain, AI, and digital marketplaces that facilitate MaaS adoption.
- Categorizing research themes, classifying existing literature into theoretical models, platform architectures, and data-driven innovations.
- Recognizing adoption challenges—including trust mechanisms, pricing models, interoperability concerns, and SME integration barriers.
- Highlighting future research directions—emphasizing the need for empirical case studies, advanced decision-support systems, and industry-wide adoption strategies.

This review directly answers the research question, showing that MaaS is evolving through Industry 4.0 technologies but faces adoption hurdles. Further research should refine trust models, pricing strategies, and sector-specific applications to accelerate MaaS integration.

MaaS enhances Industry 4.0 adoption by enabling flexible, cost-efficient manufacturing through cloud computing, AI, and blockchain. Industries like automotive and healthcare benefit from on-demand production and supply chain agility, reducing costs and lead times. Adapting digital infrastructure and workforce skills is key to maximizing its potential.

6.2. Limitations and Indicative Extentions

While this review offers a comprehensive analysis of MaaS research, it is limited by reliance on the Scopus database, potentially excluding relevant studies. Additionally, bibliometric methods emphasize highly cited papers, overlooking emerging research. Future studies should integrate multiple databases, apply diverse analytical techniques, and include qualitative assessments like expert interviews to ensure a more balanced perspective.

Future research should explore industry-specific case studies to validate MaaS applications. For example, automotive manufacturing could showcase decentralized production benefits, while healthcare could examine on-demand 3D printing for medical devices. Additionally, regional studies comparing MaaS adoption in developed and emerging economies could highlight key challenges and policy needs. These investigations would provide empirical insights and guide industry-specific strategies. In addition, future investigations should examine case studies in particular industrial segments, for example, automotive, foods, constructions, or healthcare, to further validate MaaS practicality and efficiency under various market demands and regional constraints.

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