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From Code to Cargo: A Bibliometric Mapping of the Metaverse Revolution in Supply Chain Management

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Abstract: *Once a notion confined to science fiction, the metaverse is rapidly becoming a transformative digital reality, merging virtual and physical spaces through advanced technologies such as virtual reality, augmented reality, artificial intelligence, blockchain, and the Internet of Things. This study investigates the metaverse's disruptive potential within supply chain management, where it enables real-time monitoring, immersive simulations, and virtual marketplaces: reshaping operational efficiency, transparency, and strategic decision-making. Using a hybrid methodology that combines bibliometric analysis via the Bibliometrix package in R Studio and network-based content analysis through VOSviewer, the study maps the evolution of academic discourse in this field. A significant rise in scholarly output was observed in 2023, reflecting accelerating global interest. The analysis identifies leading countries such as the United States, Germany, and China, along with top-contributing institutions like Chang Gung University and Sungkyunkwan University. Prominent themes include "virtual reality," "augmented reality," and "digital twins," signaling the growing integration of immersive technologies into SCM processes. Uniquely, this study is among the first to systematically chart the intellectual structure of metaverse research in SCM, providing a foundational lens for future inquiry. The findings pave the way for interdisciplinary collaboration, theory development, and practical models for sustainable and ethical metaverse adoption.*

Keywords: Metaverse; Supply Chain Management (SCM); Supply Chain (SC); Technological Innovation; Virtual reality

JEL Classification: O14, O30, O31, O32, Q55

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Introduction

"The virtual world is becoming more real, and the real world more virtual."
— David Chalmers

This observation by philosopher David Chalmers aptly captures the essence of the metaverse: a digital frontier where the boundaries between the physical and virtual are rapidly dissolving. Imagine stepping into a digital universe where avatars negotiate contracts, virtual warehouses monitor shipments in real time, and procurement takes place not across boardroom tables but within immersive, interconnected environments. What once lived only in the realm of speculative fiction is now unfolding as a tangible reality.

The concept of the metaverse was first introduced by Neal Stephenson in his 1992 science fiction novel Snow Crash, where he described a three-dimensional virtual world existing parallel to the physical one. Over the years, this visionary idea has evolved into a persistent and immersive digital space enabled by advanced technologies. Today, the metaverse represents an interconnected virtual realm where individuals can develop, distribute, and consume digital artifacts (McKinsey, 2022). This innovative environment utilizes technologies such as virtual reality (VR), augmented reality (AR), artificial intelligence (AI), blockchain, and the Internet of Things (IoT), creating a fusion of the digital and physical worlds. As Maersk (2022) highlights, the metaverse signifies the next evolution of the internet, offering lifelike personal and business experiences online. Similarly, Lovich (2022) describes the metaverse as combining VR and mixed reality (MR) worlds, enabling real-time interactions across distances via browsers or headsets.

The metaverse has rapidly garnered global attention, reflected in substantial investments. In 2021 alone, metaverse-related companies raised over $10 billion, doubling the previous year's investments, and by 2022, investments had soared to over $120 billion (McKinsey, 2022). The latest McKinsey research projects that the metaverse could generate up to $5 trillion in value by 2030, underscoring its transformative potential. As a novel idea rooted in cutting-edge technology, the metaverse can reshape global relationships, redefine communication dynamics, and break down physical barriers. Within this digital universe, individuals interact as avatars: virtual embodiments of their identities, providing new opportunities for social and professional engagement. However, Gao et al. (2024) point out, the metaverse is characterized by its perpetual flux and unpredictability, presenting opportunities and challenges.

Recent scholarly interest has turned toward the potential of the metaverse to revolutionize industries, particularly supply chain management (SCM). As Wang et al. (2023) suggest, the metaverse offers unprecedented advantages in SCM, including real-time monitoring of products and services, enhanced transparency, cost savings, and operational efficiency. Virtual marketplaces within the metaverse facilitate

optimized interactions between buyers and sellers, enabling procurement strategies that surpass traditional methods in speed and cost-effectiveness. Moreover, the metaverse provides a platform to simulate supply chain scenarios, test innovative technologies, and predict challenges, allowing for the optimization of processes before their real world implementation.

Beyond SCM, the metaverse holds significant implications for other sectors, such as adult education. Tlili et al. (2022) argue that the metaverse can accelerate the integration of emerging technologies, such as AI, blockchain, AR, and edge computing while addressing barriers like limited time, geographical constraints, and financial limitations. However, the unchecked growth of the metaverse also presents critical risks, including data security challenges, identity theft, and unauthorized access. The absence of a global regulatory framework exacerbates these risks, creating utopian and dystopian possibilities. To mitigate these challenges, the concept of a "Trusted Metaverse" has emerged, emphasizing the collaborative roles of companies, consumers, and regulators in ensuring the integrity and security of this digital ecosystem.

Against this backdrop, the present study aims to explore the academic landscape surrounding the metaverse's integration into supply chain management (SCM), guided by the following research questions:

Research Question 1: What is the current publishing trend regarding the metaverse in the field of SCM?

Research Question 2: Within the field of SCM, who are the notable contributors in metaverse research, including authors, companies, and nations?

Research Question 3: Which texts are frequently referenced in metaverse-related research in SCM?

Research Question 4: What are the prevailing trends in scholarly literature concerning the integration of the metaverse in SCM?

Research Question 5: What significant research clusters exist in this field, and what are the promising directions for future research on the integration of the metaverse in SCM?

To address these questions, this paper adopts a structured approach: beginning with presenting the background and methodological approach of the study, followed by a detailed analysis of the findings. The final sections present the managerial implications and conclusions, offering a forward-looking perspective on how the metaverse can reshape the future of supply chain ecosystems. Unlike earlier works that primarily examined the conceptual or technological aspects of the metaverse within individual industries, this study distinguishes itself through its systematic, data driven exploration of the metaverse's integration into supply chain management (SCM). Utilizing a hybrid methodology: combining bibliometric analysis via *Bibliometrix* in R and network-based content mapping through *VOSviewer*, the study transcends case-based discussions to deliver a comprehensive, macro-level view of global scholarly discourse. It identifies key publication trends, intellectual clusters, and international

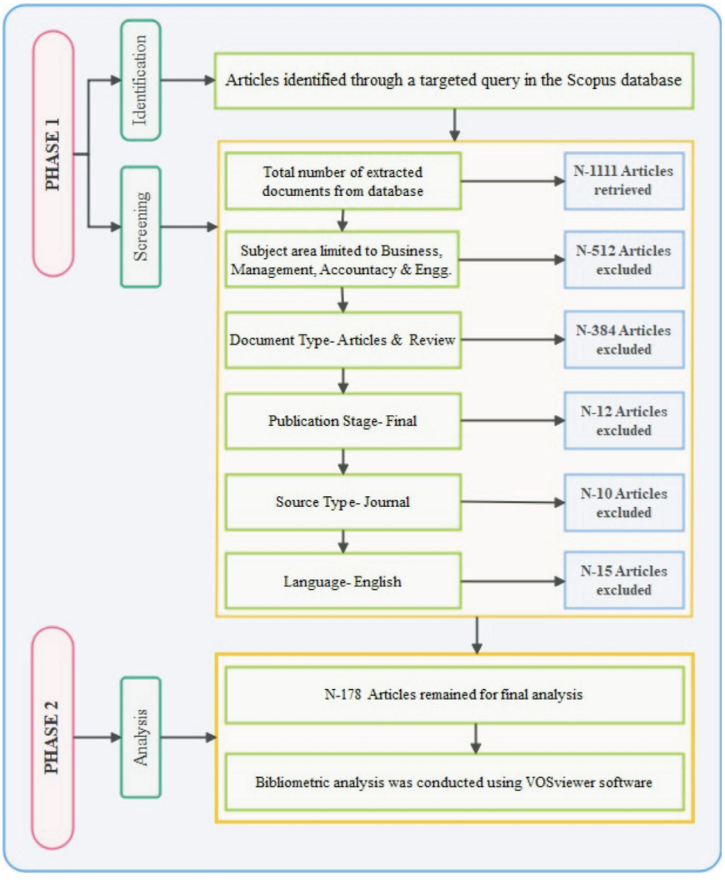
collaborations, offering one of the first bibliometric mappings of the metaverse's role in SCM. By doing so, it lays the groundwork for future interdisciplinary research and strategic decision-making, contributing both theoretical and practical insights to this rapidly evolving domain.

Research Methodology

This study adopts a systematic and methodical approach to collecting, analyzing, and synthesizing existing literature on the metaverse within the context of supply chain management (SCM), using PRISMA framework. By combining a domain-based literature review with bibliometric and content analysis, this hybrid methodology facilitates a quantitative and qualitative exploration of the research landscape. This dual approach allows the study to assess the scope and impact of existing research while capturing broader trends and emerging insights within this rapidly evolving field (Tiwari et al., 2017). Bibliometric analysis forms the core of this research methodology, offering a quantitative means of measuring publication impact and identifying research trends (Ikpaahindi, 1985). As Milian et al. (2019) highlight, bibliometric methods are particularly effective in addressing the growing literature within a research domain. While they do not replace conventional literature review techniques, bibliometric methods serve as complementary tools, providing a structured framework for understanding the research landscape (Feng et al., 2017). To enhance the robustness of this study, bibliometric analysis was integrated with detailed content analysis of selected articles, ensuring a holistic and nuanced examination of the metaverse's role in SCM. The bibliographic data for the analysis were extracted and processed using R software's "bibliometrix" package (Aria & Cuccurullo, 2017) and VOSviewer software (Van Eck & Waltman, 2010). The bibliometrix package facilitated in-depth bibliometric evaluations, including trend analysis, citation networks, and co-authorship patterns. Meanwhile, VOSviewer was utilized for network visualization, identifying co-citation relationships, keyword co-occurrence, and collaborative networks. These tools allowed the study to uncover thematic clusters and intricate connections within the literature, providing meaningful insights into the evolution of research in this domain. The Scopus database was selected as the primary data source owing to its extensive coverage of over 20,000 peer-reviewed journals across diverse disciplines, including social sciences, technology, and the arts and humanities (Fahimnia et al., 2015).Scopus is recognized as being more comprehensive than other databases, such as Web of Science (Yong-Hak, 2013), making it an ideal resource for this study. A targeted search query using the TITLE-ABS-KEY fields in Scopus initially yielded 1,111 documents. To ensure relevance, only documents directly related to SCM were retained, focusing on the subject areas of Engineering and Business, Management, and Accountancy. This filtering process excluded

512 unrelated documents, resulting in a final dataset of 178 publications for detailed analysis. Content analysis was conducted on a subset of the dataset to supplement the bibliometric analysis. This qualitative approach enabled a deeper examination of the themes, methodologies, and findings presented in the selected articles. By integrating insights from bibliometric analysis with the qualitative depth of content analysis, the study ensured a comprehensive understanding of the metaverse's applications and implications for SCM. This dual approach validated the bibliometric findings and identified specific contributions, gaps, and future research opportunities. The bibliometric examination encompassed various aspects of metaverse-related research in SCM, including publication trends, key contributors (authors, institutions, and countries), frequently referenced texts, and thematic areas. The analysis was enriched by the use of advanced software tools, with the bibliometrix package enabling detailed

Figure 1: Methodical approach for bibliometric analysis



Source: Author's own work.

bibliometric evaluations and VOSviewer mapping collaborative patterns and thematic clusters (Guleria & Kaur, 2021). These tools provided critical insights into the research landscape and the emerging connections within the domain. By leveraging the strengths of bibliometric and content analysis, this methodology captures the research landscape's quantitative and qualitative dimensions. This approach highlights the transformative potential of the metaverse and identifies opportunities for future exploration in this interdisciplinary domain.

Findings

Annual Publication Productivity

An initial examination of the literature provides a fundamental understanding of publishing trends and the growth of scholarly interest in the metaverse within the context of supply chain management (SCM). As Khalid et al. (2015) noted, such an analysis offers a crucial starting point to evaluate the volume and trajectory of research in a specific domain. One key indicator of research productivity is the annual publication count, which reflects the scholarly community's engagement with the topic over time. The data presented in Table 1 and visualized in Figure 2 illustrate the publication trends from 1998 to 2023. The first documented publication on the metaverse appeared in 1998, marking the beginning of academic exploration in this field. Over the years, the volume of publications has fluctuated, reflecting varying levels of interest and advancements in the underlying technologies associated with the metaverse.

Notably, 2023 witnessed the highest number of publications, with thirty-eight documents recorded, signifying a significant surge in scholarly activity and interest. This peak aligns with the recognition of the metaverse's transformative potential and integration into diverse fields, including SCM.

Conversely, 2014 recorded no publications on the topic, indicating a period of stagnation or a shift in academic focus during that time. The absence of publications in certain years highlights the non-linear progression of research interest, which may be influenced by technological developments, funding priorities, or shifting scholarly interests.

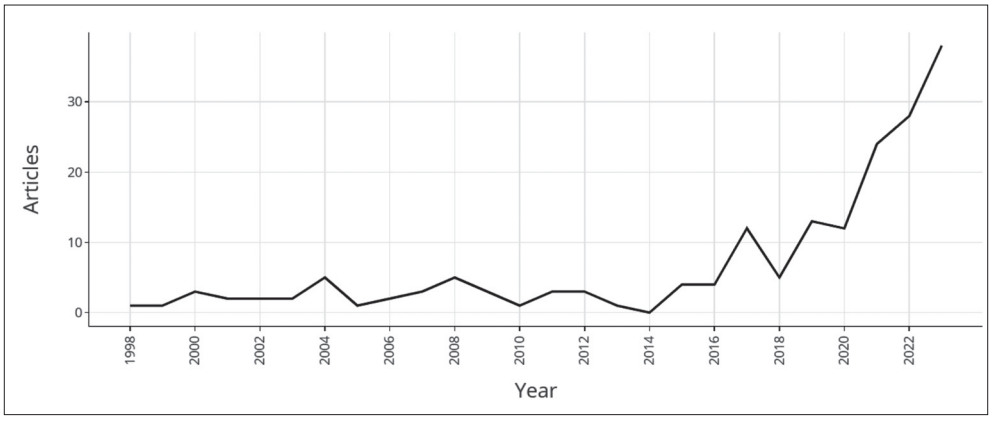
The analysis reveals the dynamic and evolving nature of research on the metaverse in SCM. The upward trend in recent years suggests a growing acknowledgment of its importance, particularly as advancements in virtual reality, blockchain, artificial intelligence, and other enabling technologies continue to accelerate. This increase in publications underscores the expanding scope of applications for the metaverse and its potential to reshape SCM practices, making it a pivotal study area for future research.

Table 1: Overview of publications

Year	Articles
1998	1
1999	1
2000	3
2001	2
2002	2
2003	2
2004	5
2005	1
2006	2
2007	3
2008	5
2009	3
2010	1
2011	3
2012	3
2013	1
2014	0
2015	4
2016	4
2017	12
2018	5
2019	13
2020	12
2021	24
2022	28
2023	38

Source: Author's own work.

Figure 2: Overview of published works.



Source: Biblioshiny

Country-Wise Productivity

Country-level analysis of publication and citation data provides valuable insights into the geographic distribution of scholarly contributions and influence in the domain of metaverse research in supply chain management (SCM). Country production, which combines the volume of publications and their corresponding citations, reflects the quantity and impact of research output from specific nations.

As illustrated in Figure 3, the United States is the leading contributor in publications and citations. With twenty-five publications and an impressive 667 citations, the United States is dominant in advancing metaverse-related research. This leadership stems from the country's robust academic infrastructure, technological innovation, and active involvement of key industries and research institutions in exploring metaverse applications.

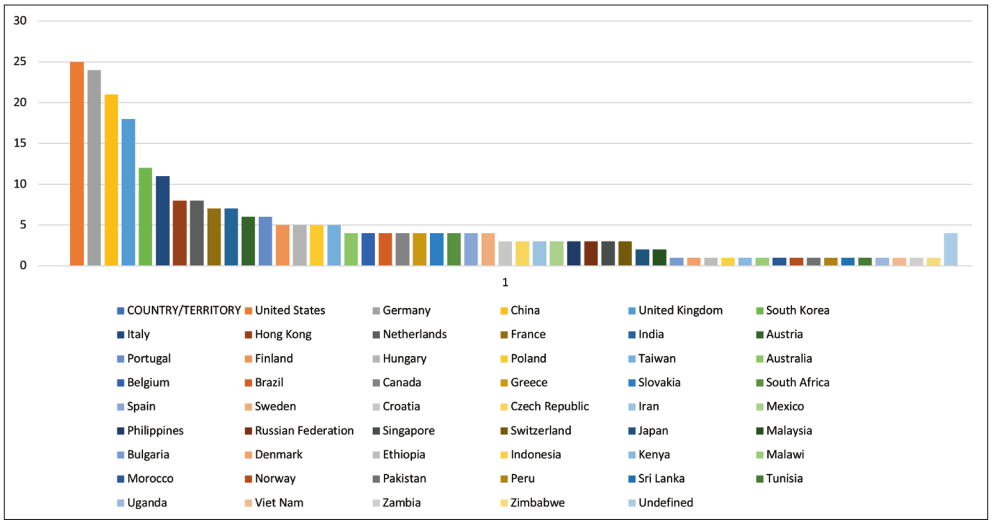
Germany ranks second in overall productivity, with twenty-four publications and 613 citations. This close alignment in both publication volume and citation impact underscores Germany's significant contributions to the field, particularly in areas such as engineering and industrial applications, which are closely tied to supply chain innovations.

China secures the third position in volume, contributing twenty-one publications. While the citation data for China is less prominent than the United States and Germany, the nation's growing academic and industrial investment in metaverse technologies indicates its increasing influence in this domain.

Interestingly, the United Kingdom ranks third in citations, with 578 citations, despite not being among the top three countries for publication volume. This suggests that research originating from the United Kingdom has a high impact, with its publications being widely referenced and influential in shaping the discourse on metaverse applications in SCM.

This analysis highlights the geographic concentration of impactful metaverse research in a few leading nations, with the United States, Germany, China, and the United Kingdom playing pivotal roles. The findings emphasize the importance of international collaboration and knowledge exchange to enrich the global understanding of the metaverse's potential in supply chain management further. Additionally, the citation data provides evidence of the high-quality and impactful nature of research emanating from these nations, which serves as a benchmark for other countries aiming to strengthen their contributions to this evolving field.

Figure 3: Plot illustrating document analysis by country.



Source: Author's own work.

Affiliation-Wise Productivity

Affiliation-based citation analysis sheds light on the contributions of academic institutions to the body of research on the metaverse within the context of supply chain management (SCM). By examining the cumulative citations associated with institutions, this analysis identifies key players in advancing research in this domain and highlights the institutions' influence and academic productivity.

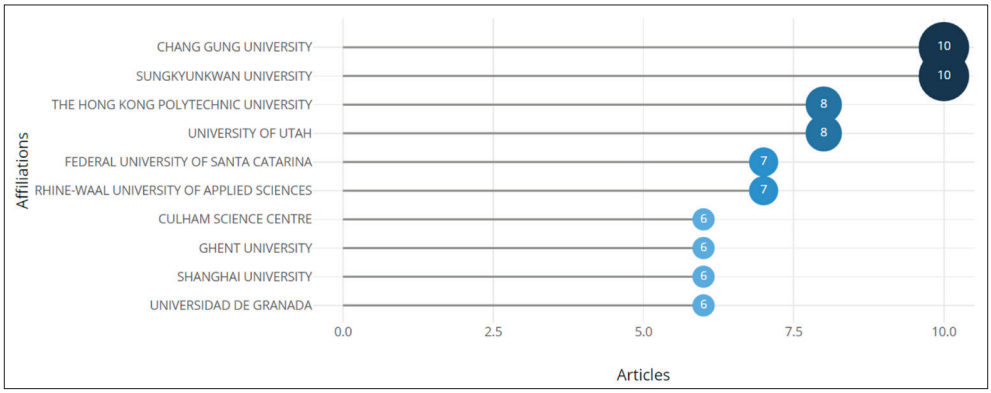
Figure 4 reveals that Chang Gung University and Sungkyunkwan University lead in the number of publications, with each institution contributing ten documents. This prominent position underscores their active involvement and leadership in metaverse-related research, particularly within SCM. Their contributions stem from institutional solid support for cutting-edge research and collaboration with industry partners exploring the metaverse's practical applications.

Other institutions, while different from the publication volume of the top two, have also made notable contributions, with publication counts ranging from eight to six documents. These institutions represent a diverse pool of academic contributors actively shaping the research landscape of metaverse applications in SCM. Though slightly smaller in volume, their efforts collectively add depth and diversity to the body of literature, enriching the discourse with varied perspectives and methodologies.

Chang Gung University and Sungkyunkwan University not only lead in publication volume but also influence research directions and foster interdisciplinary collaboration. Their contributions are instrumental in driving the continuous evolution

of metaverse technologies and their integration into SCM, emphasizing the global importance of this transformative research area. This institutional engagement is vital for continuously evolving and applying metaverse technologies in supply chain management, reflecting the growing global interest in this transformative study area.

Figure 4: Plot representing document analysis by affiliation.



Source: Bibliophagy

Author Productivity

The analysis of author productivity provides insight into the contributions and impact of individual scholars within the domain of metaverse studies, particularly in the context of supply chain management (SCM). By evaluating the total number of publications and citations associated with prominent authors, the study identifies key contributors and highlights the influence of their work.

As detailed in Tables 2 and 3 and depicted in Figure 5, several authors, including Arranz, F., De Baets, B., De Meulenaer, B., Devlieghere, F., Fischer, G., Heemskerk, C., Keogh, J.G., Lehmann, T., Ragaert, P., and Rauscher, F., each have two published works, marking them as consistent contributors to the metaverse research domain. While these authors share an equal number of publications, their overall impact varies, as measured by citation counts.

The analysis further identifies a subset of highly influential authors based on citation metrics. Panetto H., Iung B., Ivanov D., Weichhart G., and Wang X. collectively hold the highest citation count of 204, reflecting the substantial impact and recognition of their work within the field. Their research likely addresses foundational or high-impact topics that resonate widely with the scholarly community and practitioners.

Following this group, McMullen P.R. ranks as the second most-cited author, with a total of 174 citations, demonstrating significant academic influence. Similarly, Cai

Y.-J. and Lo C.K.Y. hold the third position with 153 citations, further underscoring their contributions to advancing the discourse on metaverse applications in SCM.

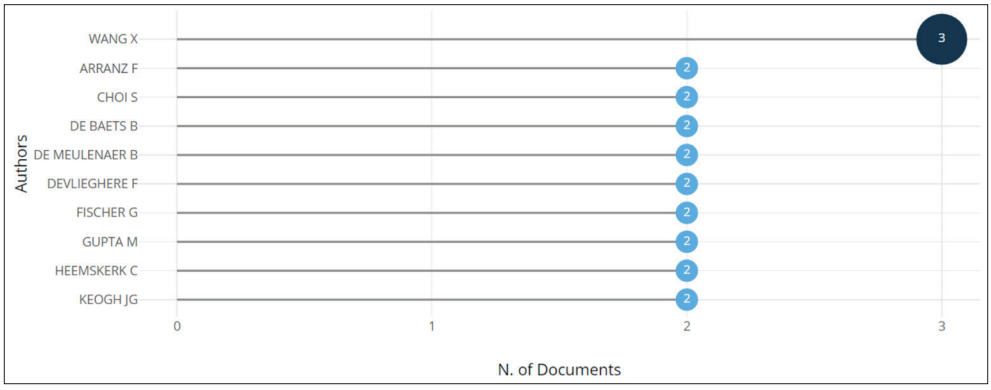
This analysis reveals a concentrated group of scholars whose research has played a pivotal role in shaping the field. The disparity between the number of publications and citations highlights the distinction between productivity and impact, suggesting that while many authors actively publish, a smaller subset achieves a higher level of influence through widely cited and impactful work. This underscores the importance of not only publishing frequently but also addressing significant research gaps and producing high-quality, relevant studies that drive innovation and understanding in this emerging field.

Table 2: Analysis of author productivity

Authors	Articles	Articles Fractionalized
WANG X	3	0.68
ARRANZ F	2	0.29
CHOI S	2	0.57
DE BAETS B	2	0.33
DE MEULENAER B	2	0.33
DEVLIEGHERE F	2	0.33
FISCHER G	2	0.29
GUPTA M	2	1.00
HEEMSKERK C	2	0.19
KEOGH JG	2	0.50

Source: Biblioshiny

Figure 5: Plot illustrating document analysis by author.



Source: Biblioshiny

Table 3: Table depicting the Analysis of Documents~ Author~Year~Citation

Authors	Title	Year	Source Title	Cited by
Panetto H.; Iung B.; Ivanov D.: Weichhart G.; Wang X.	Challenges for the cyber-physical manufacturing enterprises of the future	2019	Annual Reviews in Control	204
McMullen P.R.	An ant colony optimization approach to addressing a JIT sequencing problem with multiple objectives	2001	Artificial Intelligence in Engineering	174
Cai Y. -J.; Lo C.K.Y.	Omni-channel management in the new retailing era :A systematic review and future research agenda	2020	International Journal of Production Economics	153
Behzadan A. H.; Aziz Z.; Anumba C. J.; Kamat V. R.	Ubiquitous location tracking for context specific information delivery on construction sites	2008	Automation in Construction	140
Nikolakis N.; Alexopoulos K.; Xanthakis E .: Chryssolouris G.	The digital twin implementation for linking the virtual representation of human-based production tasks to their physical counterpart in the factory-floor	2019	International Journal of Computer Integrated Manufacturing	135
Wang C.; Blei D.M.	Variational inference in nonconjugate models	2013	Machine Learning Research	130
Lovreglio R.: Fonzone A.: dell''Olio L.	A mixed logit model for predicting exit choice during building evacuations	2016	Transportation Research Part A: Policy and Practice	111
Ullah I.; Shen Y.: Su X.: Esposito C.; Choi C.	A Localization Based on Unscented Kalman Filter and Particle Filter Localization Algorithms	2020	IEEE Access	82
Bressanelli G.; Pigosso D.C.A.; Saccani N.: Perona M.	Enablers, levers and benefits of Circular Economy in the Electrical and Electronic Equipment supply chain: a literature review	2021	Journal of Cleaner Production	77
Wong FLY.	Influence of Pokémon Go on physical activity levels of university players: A cross-sectional study	2017	International Journal of Health Geographics	72

Source – Author's own work

Word Cloud

Figure 6 depicts the analysis of word frequency trends over time, highlighting the evolution of research topics and themes. One noticeable observation is the significant increase in the keyword "virtual reality" frequency from 1998 to 2023. The frequency rises sharply from 1 to 103, indicating this research area's growing interest and prominence over the years. Furthermore, the analysis reveals similar increasing trends for keywords such as "augmented reality" and "supply chain management."

The increasing frequency of "virtual reality" suggests that it has emerged as a prominent and burgeoning research topic within the field under study. This trend aligns with the growing significance of virtual reality technologies across various domains,

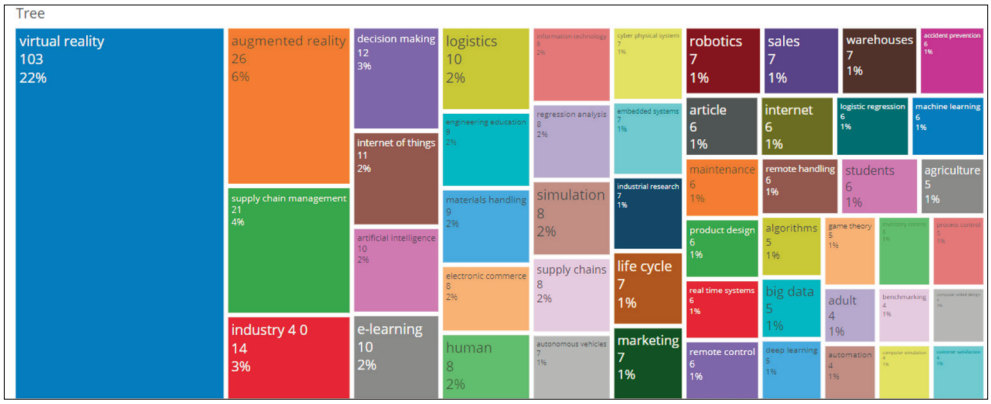
including but not limited to education, healthcare, entertainment, and industrial applications. The increasing frequency of "supply chain management" reflects the growing emphasis on optimizing supply chain processes and operations, particularly in globalization, digitalization, and changing consumer demands. The rising interest in supply chain management underscores its critical role in enhancing organizational efficiency, sustainability, and competitiveness in today's dynamic business environment.

Figure 6: Trends in word frequency over time

Source: Biblioshiny

Tree Map

Figure 7: Visualization using Tree Map



Source: Biblioshiny

A tree map visualization is a powerful tool in bibliometric analysis, offering a clear representation of the distribution of publications across various categories based on specific keywords or criteria. In this study, the tree map (Figure 7) illustrates the frequency of keywords associated with metaverse research in the context of supply chain management (SCM). This visualization provides valuable insights into the field's dominant themes and focus areas.

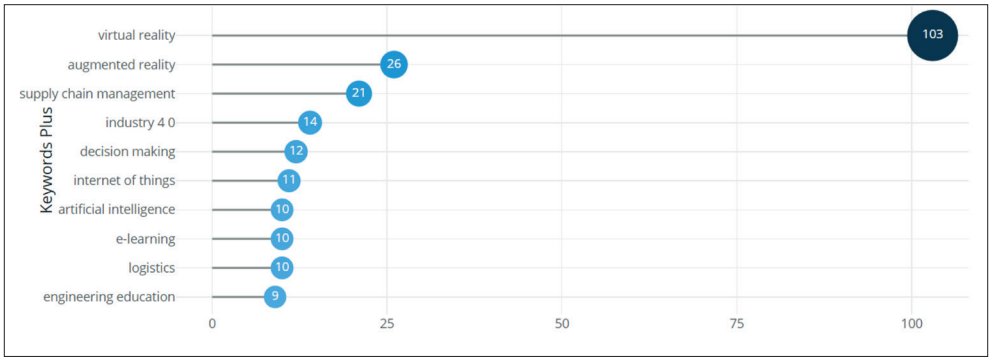
The keyword "virtual reality" emerges as the most frequently used term, appearing 103 times, making it the central theme in metaverse-related research. This high frequency highlights the critical role of virtual reality in enabling immersive experiences and its widespread applications in SCM, such as virtual training, remote operations, and simulation of supply chain processes.

Following "virtual reality," the term "augmented reality" holds the second-highest frequency, appearing twenty-six times. While less prominent than virtual reality, augmented reality significantly enhances physical environments with digital overlays, offering applications in logistics, inventory management, and worker training within SCM.

The size of each rectangle in the tree map corresponds to the number of publications associated with a specific keyword, providing a visual cue to the relative importance or popularity of themes within the research landscape. This distribution helps researchers identify the most frequently explored areas, which can guide the formulation of research questions or the design of future studies. For instance, the prominence of "virtual reality" and "augmented reality" indicates that immersive technologies are central to developing and applying the metaverse in SCM.

Most Relevant Words

Figure 8: Frequency distribution of relevant terms



Source: Biblioshiny

The plot in figure 8 reveals the frequency of occurrence for various relevant words, with "virtual reality" being the most prevalent term, occurring 103 times. This is followed by "augmented reality," "supply chain management," "industry 4.0," and numerous other terms, each indicating varying degrees of prominence within the dataset or field under study.

This observation aligns with the growing interest and adoption of virtual reality technologies across various sectors, indicating its potential to revolutionize numerous aspects of human interaction, education, entertainment, and industry.

Similarly, the presence of "augmented reality," "supply chain management," and "industry 4.0" among the most relevant words underscores their importance and relevance within the examined context. Augmented reality, like virtual reality, is experiencing increased attention due to its potential applications in diverse fields such as gaming, education, healthcare, and manufacturing.

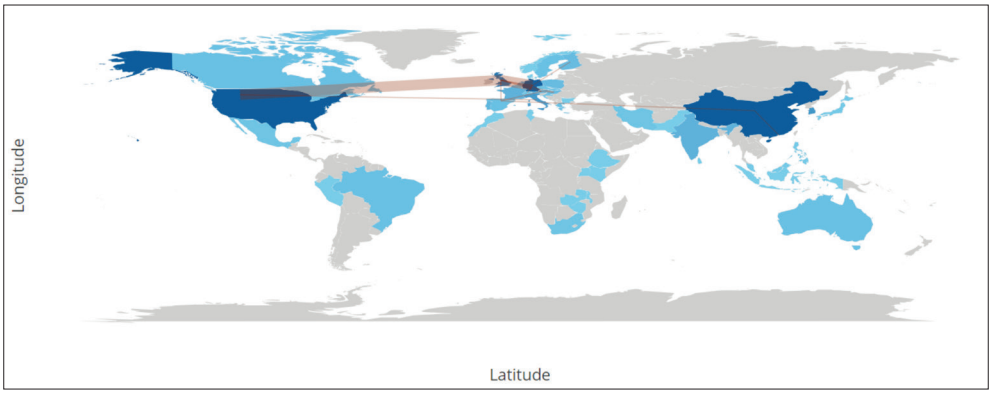
Supply chain management and industry 4.0 indicate the growing emphasis on optimizing operational processes and leveraging advanced technologies to enhance efficiency, productivity, and competitiveness within industrial settings.

Countries Collaboration World Map

As illustrated in Figure 9, the analysis of country collaborations offers insights into the collaborative dynamics within the international scientific community, highlighting the active involvement of different countries across specific research domains. The findings indicate notable collaboration patterns, with Germany showing collaboration primarily with the United Kingdom, followed by the United States with the United Kingdom and Italy, and the United Kingdom with the Netherlands, Hungary, France, and Austria. Moreover, collaborations from Germany extend to Switzerland, the Netherlands, Finland, and Austria, while France collaborates with Austria, and China collaborates with both Hong Kong and France. Additionally, Austria is seen collaborating with Hungary.

Overall, the robust collaboration networks between countries such as the United States and the United Kingdom and Germany and the United Kingdom suggest efficient research practices facilitated by shared resources and expertise exchange among these nations.

Figure 9: World map of international collaborations



Source: Biblioshiny

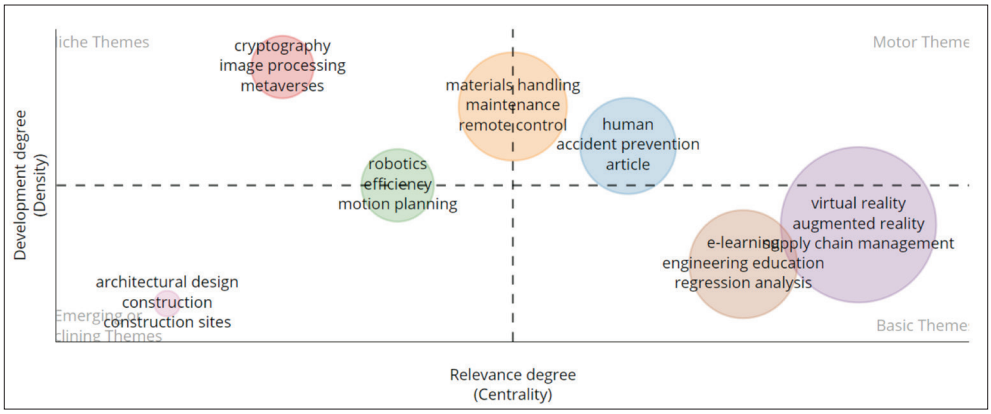
Thematic Map

Figure 10 illustrates the results of a thematic map analysis to identify the primary themes in metaverse impact on supply chain management. This examination utilized 233 authors' keywords and applied a minimum cluster frequency of ten, leading to the emergence of seven clusters on the map. Among these clusters, "virtual reality" stands out as the most significant, with 520 cluster frequencies, followed by "materials handling" and "e-learning," each with 114 and 113 cluster frequencies, respectively.

The map evaluates themes based on two dimensions: centrality and density, which assess the significance and sustainability of a theme in advancing a particular area. The cluster associated with "virtual reality" and "materials handling" resides in the high density and centrality quadrant. This positioning suggests strong interconnections with other themes in the field, indicating a cohesive network among the keywords within this cluster. Notable keywords within this cluster include "augmented reality," "supply chain management," "maintenance," and "remote control."

Conversely, the "architectural design" cluster occupies the quadrant with low density and centrality, signalling a decline in relevance within the domain. Additionally, the analysis indicates that the "construction sites" cluster exhibits the lowest density. Lastly, the thematic map suggests that the "metaverses" cluster partly falls within the fourth quadrant, implying its importance to the domain and highlighting the need for further development and increased research attention.

Figure 10: Map illustrating themes.



Source: Biblioshiny

Bibliometric Coupling

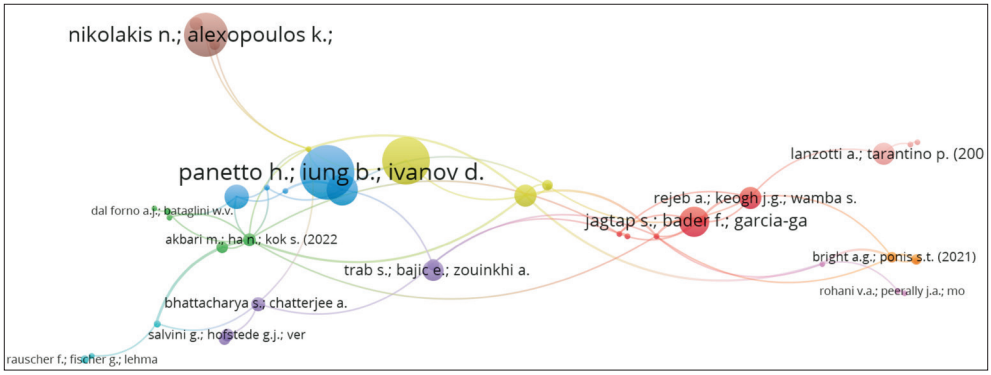
Bibliographic coupling is a method used to explore the relationships between documents that cite a common third source, thereby uncovering shared foundations and thematic overlaps within a research domain. This approach enabled a detailed examination of the interconnections and influence of critical documents within the field. From a dataset of 178 documents, 102 met the threshold of having at least five citations, underscoring their prominence and interconnectedness in the scholarly landscape. These selected documents formed ten distinct clusters, comprising 43 items in total. The coupling network was further characterized by 114 total links and a cumulative link strength of 166, illustrating the intricate web of relationships and the extent of shared references among the documents. The analysis emphasized citation count as a weighting criterion to ensure that highly influential documents were adequately represented in the bibliometric map. To cluster items effectively, data was normalized using the association method, which calculates linkage strength relative to other connections. A random seed value of 0 was applied to maintain consistency and reproducibility, and the algorithm iterated ten times to refine and optimize the clustering process.

The findings are visually represented in Figures 11 and 12, where nodes symbolize individual documents, and their size correlates with citation counts.

Lines connecting the nodes indicate bibliographic coupling relationships, with the thickness of the lines representing the strength of shared references. These visualizations provide a clear and organized view of the bibliometric landscape, revealing the thematic alignments and interconnections among the analyzed documents. The identified clusters offer a structured perspective on the research domain, with each cluster

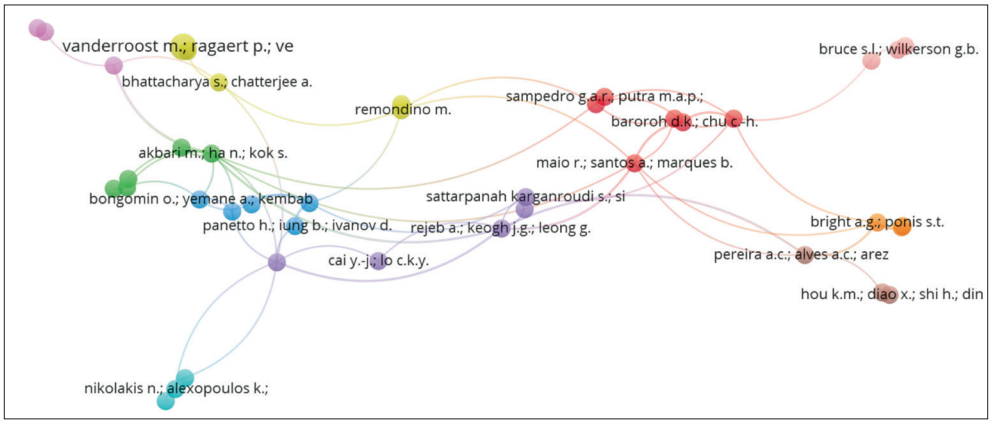
representing a cohesive group of documents that share a common research focus or foundational references. These clusters highlight thematic diversity and uncover the structural relationships within the research field.

Figure 11: Bibliometric coupling analysis



Source:VOS viewer

Figure 12: Bibliometric coupling through examination of interconnecting lines



Source:VOS viewer

Content Analysis

Following a comprehensive evaluation of research content and topic areas, six distinct subjects have been identified, corresponding to six thematic clusters (Figure 13). These clusters represent the major focus areas within metaverse-related research in supply chain management (SCM), reflecting the diversity and depth of the field. Below is an overview of the six clusters and their thematic contributions:

Cluster 1: Emerging Technologies and Sustainability
This cluster encapsulates the transformative power of emerging technologies that drive innovation and promote sustainability across industries. Artificial Intelligence (AI) serves as a cornerstone by enabling data-driven decision-making and automation, facilitating predictive analytics and personalized business solutions. Big Data complements AI by offering the capability to analyze vast volumes of information, allowing organizations to derive actionable insights that enhance operational efficiency and customer engagement. Digital Transformation further redefines business models and operations, integrating digital tools to achieve streamlined processes and enhanced productivity. The Internet of Things (IoT) adds another layer of connectivity, linking devices and systems for real-time monitoring and seamless communication, optimizing operations across industries. Machine Learning, a subset of AI, focuses on creating adaptive systems that refine predictions and decision-making through continuous learning. The Metaverse introduces immersive virtual environments that merge the physical and digital worlds, fostering collaboration and innovation. Finally, Sustainability underscores the application of these technologies to reduce environmental impacts and build eco-friendly practices, marking a pivotal shift toward green solutions in the industrial landscape.

Cluster 2: Systems Integration and Virtualization
The second cluster focuses on integrating physical systems with advanced computational technologies, creating virtualized environments that enhance efficiency and adaptability. Cyber-Physical Systems represent this convergence, enabling real-time interaction between physical processes and digital systems, a foundation for smart manufacturing and automation. Digital Twins, virtual replicas of physical assets, offer a robust simulation, testing, and optimization platform without the risks associated with real-world experimentation. Extended Reality (XR), encompassing Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), provides transformative tools for training, operational enhancement, and design improvements. Mixed Reality bridges the gap between real and virtual environments, enabling innovative and collaborative experiences. Simulation technology allows businesses to evaluate scenarios and improve decision-making while minimizing potential risks. The supply chain, a critical operational area, benefits from these technologies by becoming more resilient, transparent, and efficient, ensuring robust and agile responses to global challenges. This cluster underscores the power of virtualization and digitization in revolutionizing traditional systems.

Cluster 3: Industry 4.0 and Augmented Experiences
This cluster centers on the technological advancements by Industry 4.0, emphasizing integrating smart technologies to enhance industrial processes. Augmented Reality (AR) plays a transformative role by overlaying digital information onto the physical

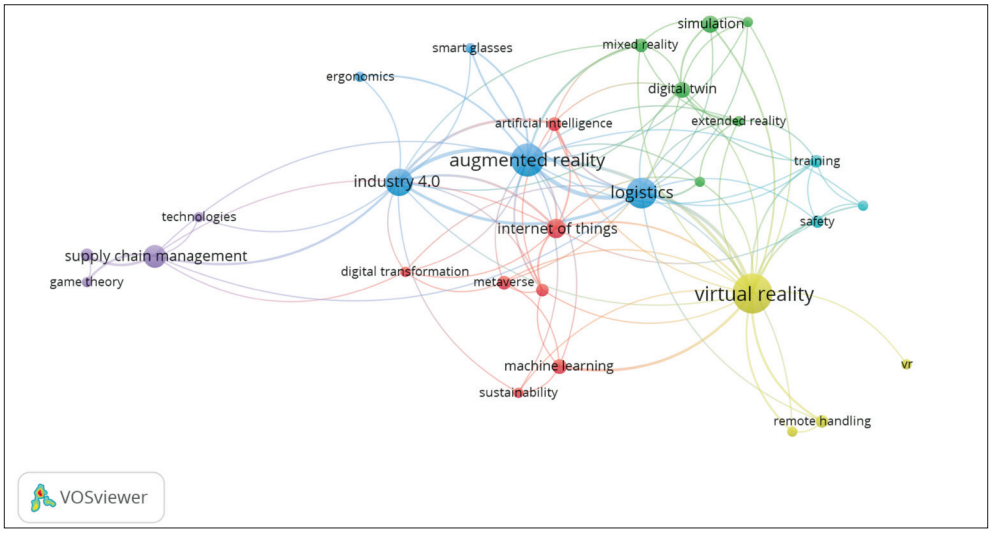
world, revolutionizing training, maintenance, and design workflows. Ergonomics ensures that these technological interventions align with human capabilities, focusing on optimizing comfort, safety, and productivity in workplaces. Industry 4.0 itself symbolizes the adoption of interconnected technologies such as IoT, AI, and robotics, creating smarter, more efficient manufacturing ecosystems. Logistics, a vital component of industry, benefits significantly from these advancements, experiencing improved efficiency in transportation, inventory management, and overall supply chain performance. Smart Glasses, as wearable technology, enhance worker productivity by providing hands free access to real-time data and instructions. Collectively, this cluster underscores the shift towards smarter, more connected, and human-centric industrial practices.

Cluster 4: Remote and Immersive Technologies
This cluster highlights the role of remote and immersive technologies in transforming industrial operations and workforce management. Maintenance practices are becoming increasingly predictive and remote, leveraging IoT and AI to reduce downtime and optimize equipment performance. Remote Handling technologies, such as robotics, enable safe and efficient management of hazardous tasks or inaccessible environments, enhancing operational safety. Virtual Reality (VR) offers immersive environments for applications like workforce training, educational programs, and operational planning, creating engaging and effective learning experiences. The broader applications of VR extend to workflow optimization and customer engagement, demonstrating its versatility in various industrial contexts. This cluster represents a shift toward immersive and remote technologies that address complex industrial challenges while prioritizing safety and efficiency.

Cluster 5: Strategic Decision-Making and Collaboration
Strategic decision-making and collaborative approaches define this cluster, emphasizing the use of advanced technologies to optimize outcomes. Game Theory introduces a structured approach to decision-making in competitive and cooperative scenarios, providing a mathematical foundation for optimizing strategies. Supply Chain Management benefits from this approach by employing strategic tools to enhance performance and responsiveness. The broad category of Technologies includes tools and methodologies that drive innovation, addressing industrial challenges through innovative solutions. Virtual Enterprise represents a collaborative framework that uses technology to bridge geographic boundaries, enabling seamless cooperation among businesses and individuals. This cluster underscores the importance of strategic and collaborative technologies in achieving organizational goals and maintaining a competitive edge.

Cluster 6: Safety and Workforce Development
The final cluster focuses on the critical aspects of safety and workforce development, highlighting the application of technology to improve workplace standards. In the construction sector, technologies are being deployed to enhance safety protocols, improve efficiency, and support sustainable practices. As a broader theme, safety involves integrating predictive analytics, monitoring systems, and training programs to mitigate risks and create secure environments. Training, a crucial component of workforce development, leverages simulation, VR, and AR to deliver hands-on and immersive learning experiences that enhance skill and readiness. This cluster emphasizes the pivotal role of technology in fostering a safe, efficient, and skilled workforce capable of meeting the demands of modern industries.

Figure 13: The interconnected network of cooccurring keywords



Source:VOS viewer

Managerial Implications

The metaverse represents a transformative opportunity for organizations to reimagine business operations, customer engagement, and global collaboration. Below are the managerial implications derived from the research findings, emphasizing strategic priorities for organizations entering or expanding within the metaverse:

- Strategic Decision-Making for Metaverse Integration
  Managers must consider the timing and scope of their organization's entry into the metaverse. This requires evaluating the organization's readiness in terms

of technological infrastructure, workforce capabilities, and cultural adaptability(Marabelli & Lirio, 2024). The guiding research questions formulated in the study provide a framework for assessing the potential benefits and challenges of metaverse adoption, helping organizations make informed strategic decisions.

- Embracing Digital Transformation
  The metaverse offers opportunities for digital transformation that go beyond traditional practices. Managers should focus on integrating advanced technologies such as VR, AR, AI, and digital twins into their operations. These tools enable real-time data analysis, immersive training, and simulation of complex processes, fostering innovation and operational efficiency.
- Enhancing Supply Chain Resilience
  The metaverse has significant potential in SCM. By leveraging virtual marketplaces, blockchain, and simulation technologies, supply chain managers can enhance transparency, efficiency, and cost-effectiveness. Real-time monitoring and predictive analytics can mitigate risks and improve decision-making, allowing supply chains to adapt to global disruptions and changing consumer demands (Zavala et al., 2018).
- Developing Workforce Competencies
  As organizations integrate the metaverse, managers must prioritize workforce development(Marabelli & Lirio, 2024). Immersive technologies such as VR and AR can be used to deliver training programs, enhance collaboration, and improve employee engagement. Preparing employees to navigate virtual environments and leverage digital tools is critical to sustaining competitive advantage in a digitally driven economy (Šímová et al., 2023).
- Building Global Customer Connections
  The metaverse enables organizations to connect with customers globally, offering new avenues for engagement and value creation (Alawadh & Barnawi, 2025). Managers can leverage virtual spaces to provide personalized experiences, expand product offerings, and foster brand loyalty. Firms should also develop services that reduce customer switching costs, ensuring long-term client retention in competitive markets.
- Navigating Ethical and Regulatory Challenges
  The metaverse introduces ethical and professional concerns related to data security, privacy, and governance. Managers must adopt robust cybersecurity measures, comply with emerging regulations, and advocate for the development of global standards. Ensuring a secure and equitable metaverse experience is essential for gaining user trust and sustaining participation (Fernandez & Hui, 2022) .
- Leveraging International Collaboration
  The study highlights the importance of global collaboration networks, with countries like the United States, Germany, and the United Kingdom leading in metaverse research and implementation. Managers should seek partnerships with

academic institutions, industry leaders, and international organizations to access shared expertise and resources, accelerating innovation and market entry.

- Innovating Product and Service Offerings
  The metaverse provides a platform for developing innovative products and services that align with customer needs. Managers can explore opportunities in virtual goods, digital identities, and immersive experiences, creating new revenue streams and competitive differentiation. Firms must also consider the remittance systems needed for seamless transactions across different metaverse ecosystems(Yoo et al., 2023).
- Addressing Post-Pandemic Business Realities
  In a post-pandemic world, the metaverse offers unique advantages for businesses transitioning from local to global operations. Managers should leverage virtual platforms to reach broader audiences, reduce operational costs, and maintain client-centric interactions despite volatile international contexts (Ali et al., 2023).
- Supporting Ethical and Sustainable Practices
  As the metaverse evolves, managers must integrate ethical considerations into their strategies. This includes addressing issues of accessibility, inclusivity, and environmental impact. Sustainability should be a core focus, leveraging metaverse technologies to promote eco-friendly practices and reduce carbon footprints across supply chains (Gómez-Zará et al., 2023; Pellegrino et al., 2023).

Conclusion

In conclusion, the metaverse, has evolved into a transformative digital reality that seamlessly integrates virtual and physical worlds through technologies like VR, AR, AI, blockchain, and IoT. This study highlights the metaverse's profound potential to revolutionize industries, with a particular focus on supply chain management (SCM). The metaverse offers unparalleled transparency, operational efficiency, and cost effectiveness by enabling real-time monitoring, virtual marketplaces, and advanced simulations (Ismail & Buyya, 2023).Through a combination of bibliometric and content analysis, this research offers a macro-level understanding of the evolving scholarly landscape, with 2023 marking a notable surge in academic output. It identifies key contributors: countries, institutions, and scholars, driving metaverse-related research in SCM, while spotlighting dominant themes such as "virtual reality," "augmented reality," and "digital twins." These insights underscore the growing academic and practical interest in immersive technologies as enablers of digital transformation within supply chains.Importantly, this study provides a structured, evidence-based framework for understanding how the metaverse is being conceptualized and applied in SCM contexts. It advocates for its strategic integration into organizational systems to foster global collaboration, workforce development, and ethical innovation:

especially critical in a post-pandemic world where digital agility and connectivity are paramount.

Building on the insights of this bibliometric and content-driven exploration of metaverse applications in supply chain management , several promising avenues for future research emerge. First, there is a critical need for meta-analytical studies that aggregate empirical findings to assess the consistency, magnitude, and contextual variations of the metaverse's impact across different SCM functions such as logistics, procurement, and inventory control. Second, theoretical contributions remain limited in current discourse; thus, future work should aim to develop robust conceptual frameworks that integrate established organizational theories: such as the Resource Based View, Institutional Theory, or the Technology Organization Environment framework, with the unique characteristics of immersive digital environments. Moreover, industry-specific comparative studies are essential to understand sectoral differences in adoption patterns and value creation, as the use of metaverse technologies in retail or healthcare supply chains may differ substantially from manufacturing contexts. There is also a pressing need to construct ROI models and performance measurement frameworks that can quantify the tangible benefits of metaverse integration in SCM operations, especially in terms of efficiency, cost savings, customer engagement, and risk mitigation. Ethical and regulatory concerns constitute another critical dimension; future studies should examine governance mechanisms, data privacy protocols, and digital labor rights to ensure equitable and secure deployment of metaverse technologies. The implications for the workforce are equally significant, necessitating research on skill development, training needs, and change management strategies for professionals operating in digitally immersive SCM settings. Additionally, the role of digital twins and real-time simulations deserves deeper investigation, particularly in optimizing forecasting, scenario planning, and operational resilience. The global nature of supply chains also invites research into how the metaverse could enhance or disrupt international collaboration, cross-border logistics, and decentralized supplier networks. Furthermore, future inquiries should explore the potential of the metaverse in driving sustainable and circular supply chain practices, leveraging virtual environments to model carbon footprints, reduce waste, and foster green logistics. Lastly, comparative bibliometric studies across disciplines could provide valuable insights into how metaverse research in SCM aligns with or diverges from its evolution in fields like education, healthcare, or marketing, thereby helping to map out interdisciplinary integration pathways.

As the metaverse continues to evolve, it holds the potential to redefine not just SCM, but the broader paradigms of organizational agility, digital interaction, and global enterprise networks. This study lays a critical foundation for both scholarly inquiry and managerial practice, offering a roadmap for navigating and leveraging the metaverse's strategic potential in shaping the future of supply chain ecosystems and beyond.

Declarations

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Conflicts of interest/Competing interests

There is no conflict of interest/Competing interests

Availability of data and material

The data supporting the findings of this study were obtained from the Scopus database and subsequently filtered based on the specific context and objectives of the research.

Code Availability

The bibliometric and content analyses were carried out using standard bibliometric tools, including VOSviewer. The results produced by these tools are presented in the tables and figures within the manuscript. No proprietary or custom-developed code was used in this study.

Authors' Contributions

Shobhanam Krishna led the methodology design, performed the data analysis, and was responsible for drafting the manuscript. **Anita Choudhary** contributed to the development of the introduction and literature review sections. **Prof. Rohit Dwivedi** provided overall conceptual guidance and conducted thorough proofreading and critical review of the manuscript. All authors have read and approved the final version of the manuscript.

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