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INDUSTRIAL METAVERSE IN SUPPLY CHAIN MANAGEMENT: APPLICATIONS, CONCEPTS, AND OPEN RESEARCH PATHS

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ABSTRACT

This research study examines the applications of the industrial metaverse in supply chain management. Thus, it reviews and analyzes the up-to-date knowledge along the Supply Chain Operations Reference Model. Therefore, a structured literature review is conducted. We derive six core functionalities of the industrial metaverse in supply chains: visibility and monitoring, prediction, simulation, collaboration, training, and optimization. Furthermore, their presence along the different phases of a supply chain is investigated. Besides the functionalities, the relationship between the industrial metaverse and simulation applications and digital twins is analyzed, and a brief description of possible metaverse architectures is provided. This study additionally derives research gaps within the emerging field of metaverse applications and research and defines paths to tackle them.

1 INTRODUCTION

The metaverse is an emerging concept for integrating the physical and digital worlds (Dwivedi et al. 2022). Its application in private contexts in connection with social media is already widespread (Statista 2022). Yet, in industrial environments, it appears as a game changer; nevertheless, it has not reached a fully operative status within the industry (Ball 2022). Especially in logistics, the metaverse has only begun to interrupt the classical processes (Tan et al. 2023). Thus, applying the metaverse, or more precisely, the industrial metaverse, to logistics promises interesting opportunities and use cases. Yet, it seems unclear how the application should be designed and implemented. Therefore, this research tackles the open spot and aims to consolidate the emerging knowledge about the industrial metaverse. Thus, two research objectives (ROs) drive this study:

RO 1: Review and analyze the state of the art of the industrial metaverse in logistics and supply chain management.

Thus, the knowledge is to be retrieved and along a framework for supply chain management analyzed.

RO 2: Derive research paths for future exploration.

This objective serves as a guideline for the community working on the industrial metaverse. To achieve the ROs, this paper is structured as follows: First, the theoretical background on the industrial metaverse and supply chain management (SCM), including the Supply Chain Operations Reference Model (SCOR model), is provided. The research method, a structured literature review (SLR), is outlined after that, and the literature search results can be found in Section 4, where the observations are described and analyzed. The review closes by providing paths for future research on the industrial metaverse in logistics (Section 5) and concludes in Section 6. The industrial metaverse and SCM will be defined in the following to lay the theoretical foundation for this work.

2 THEORETICAL BACKGROUND

This section provides state-of-the-art information for the SCM and the industrial metaverse.

2.1 Supply Chain Management and SCOR Model

A supply chain is a network of organizations combined along the value chain (Christopher 2008). The administration of such a network is called SCM (Voigt et al. 2018). Thereby, it integrates functions of inter-organizational business processes (Vitasek 2013). The core tasks of the SCM are planning, controlling, and monitoring a supply chain (Christopher 2016). It predicts, simulates, optimizes, and requires the collaboration of the supply chain partners (Christopher 2016; Lambert 2014). These purposes shall act as core functionalities within the theoretical framework for analysis. Thus, we define them as follows:

Prediction: Any processes that are “predictive analytics to refer to the building and assessment of a model aimed at making empirical predictions” (Shmueli and Koppius 2011, p. 555).

Simulation: Any process that represents “a system with its dynamic processes in an experimental model to reach findings which are transferable to reality; in particular, the processes are developed over time” (Verein Deutscher Ingenieure 2014, p. 3).

Optimization: Any process that is “the process of finding the best possible solution to a problem. In mathematics, this often consists of maximizing or minimizing the value of a certain function, perhaps subject to given constraints” (Oxford Reference 2024, n. pag.).

Collaboration: Any process that “promotes collaboration between a company and its customers and suppliers through the use of modern information technologies, integrating internal and cross-company business processes” (Krieger 2018, n. pag.).

The SCOR model, or short, just SCOR, is a reference architecture to structure these tasks and properties. SCOR was implemented in 1996 and is still up-to-date due to its continuous development. It contains the five phases of plan, source, make, deliver, and return, describing the different aspects of a supply chain. (Association for Supply Chain Management 2017)

Thus, as a reference architecture, it allows for structuring processes and objects concerning the supply chain (cf. Lugaresi et al. 2023; van der Valk et al. 2022), making it appropriate to classify the industrial metaverse’s applications in SCM in the following.

2.2 Industrial Metaverse

The industrial metaverse is a concept that is still developing (Weinberger 2022). Nevertheless, several definitions exist. Lee et al. (2021) define the metaverse as an immersive environment for unified, permanent, and ambiguous operations. Mystakidis (2022) sees the metaverse as a virtual space that lacks clear boundaries from its physical counterpart using augmented and virtual realities (AR/VR). This connection between virtual and real spaces is the foundation of the metaverse (Lee et al. 2021; Wang, Y. et al. 2023). A metaverse includes several virtual spaces for many applications, requiring vast interoperability among the virtual spaces (Dionisio et al. 2013; Weinberger 2022). The virtual spaces enhance the physical ones and work autonomously (Dionisio et al. 2013; Wang, Y. et al. 2023). Yet, they rely on the users' activity and can only thrive if they contribute and create value (Hwang and Chien 2022).

Subsuming, the following definition of an industrial metaverse emerges:

Industrial Metaverse: An industrial metaverse “describes a (decentralized) three-dimensional online environment that is persistent and immersive, in which users represented by avatars can participate socially and economically with each other creatively and collaboratively in virtual spaces decoupled from the real physical world” (Ritterbusch and Teichmann 2023, p. 12373).

The industrial metaverse can synchronize physical and virtual spaces, integrate applications' data, and integrate several virtual technologies (Ning et al. 2021; Zheng et al. 2022). It closely relates to simulation and digital twins (cf. Figure 1). Thus, both are key enablers for the industrial metaverse (Zheng et al. 2022).

Simulation and digital twins allow for transparency, automation, accuracy, incorporation of lifecycle aspects, interoperability, or reliability (Banaeian Far and Imani Rad 2022). Yet, the industrial metaverse is still in its infancy, and the capabilities of simulation and digital twins must be transformed to leverage all advantages (Yao et al. 2022). Hereby, the digital twin itself can be seen as an evolutionary step of simulation (Rosen et al. 2015). Nevertheless, analogously to the industrial metaverse, digital twins substantially enhance simulation applications (Grieves 2022; van der Valk et al. 2020). For instance, they provide capabilities such as visualization abilities, downstream data processing, or multiple data in- and outputs (van der Valk et al. 2022).

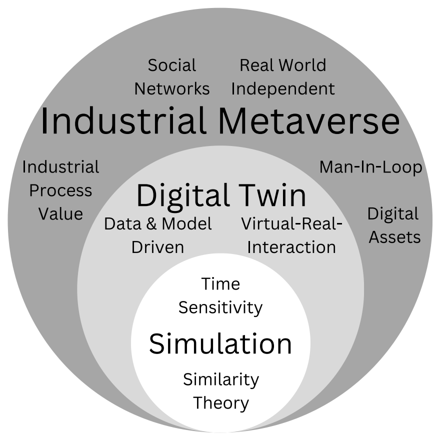


Figure 1: The Industrial Metaverse, Simulation, and Digital Twins (Zheng et al. 2022, p. 241).

Furthermore, the industrial metaverse allows users to train with it (Wang, F.-Y. et al. 2023; Zawish et al. 2024). For instance, workers may be trained for quality requirements and corresponding processes using visualization capabilities and extended realities (Tsang et al. 2022).

For the analysis of the objects, we add the functions of visualization and monitoring, and training to the core functions. They are defined as follows:

Visibility & Monitoring: Any process that "monitors and controls the material flow within the supply chain across all business functions in a short time. With the help of schematic representation of the entire network structure of a supply chain, the overview of the interdependent relationships and effects between the modules enables exceptional situations to be recognized in good time and appropriate measures to be initiated." (Betge 2006, p. 63)

Training: Any process that is "the process of learning the skills you need to do a particular job or activity" (Cambridge Dictionary 2014, n. pag.).

3 RESEARCH METHOD

According to vom Brocke et al. (2009), an SLR is carried out for this research study in five phases. These include the *definition of the review scope*, the *conceptualization of the topic*, the *literature search*, the *analysis and synthesis* phase, and the *definition of the research agenda*.

In order to achieve the RO, work on the industrial metaverse in the logistics domain is sought. The *review scope* is, therefore, focused on research outcomes and the application of the industrial metaverse in logistics. The goal is to identify central issues with as exhaustive as possible coverage (cf. Cooper 1988). To *conceptualize the topic*, the two aspects of the industrial metaverse and the logistics domain must be considered more deeply (vom Brocke et al. 2009). This includes extensions and synonyms when determining the search term for both aspects. First, in addition to the apparent term *supply chain*, a search is conducted for *logistics*, *transportation*, *inventory*, *production planning*, *supplier management*, and *demand planning*. These terms are all related to supply chains and describe a supply network and its functions on a more fine-granular level. In addition to the generic terms, this also covers other sub-disciplines of logistics. On the other hand, in addition to the *industrial metaverse*, the term *extended reality* has also been searched for in order to obtain a broader database.

The *literature search* was conducted using *Scopus*, *IEEE Xplore*, and *ACM Digital* databases. These databases cover the various relevant disciplines, from engineering to computer science. The exact number of hits can be seen in Table 1.

Table 1: Search Process.

Database	Initial Hits	Without Duplicates	Without Non-Fitting Papers
Scopus	158	158	136
IEEE Xplore	36	27	27
ACM Digital	11	7	7
Sum	205	192	170
After Analysis of Metadata and Abstract			86
After Fulltext Analysis			44

A total of 205 objects are found with the search terms applied to the title, abstract, and keywords. After the elimination of duplicates, 192 objects remain. The hits from IEEE Xplore and ACM DL are compared with the ones from Scopus. A further 22 objects can be sorted out without in-depth analysis, as they are, for example, prefaces to journals or proceedings. For the remaining 170 items, the metadata and the abstract are analyzed for a thematic fit. This leaves 86 items that are subject to a full-text analysis. A further 42 objects are discarded because they either do not deal with the topic of metaverse or are of poor quality, e.g., lacking rigor. In the end, 44 objects are included in the analysis.

After the search, the remaining objects are *analyzed* along a theoretical framework. This framework includes the bibliographic information, e.g., the origin, year, or type of publication, i.e., conceptual, review, or experiment report. Furthermore, the domain in which the metaverse is applied and its connection to related concepts, such as digital twins and simulation, is recognized. The core element of the analysis is a conceptual matrix consisting of the SCOR phases and typical purposes of digital tools (cf. Figure 4). These purposes are derived from Section 2 and are the core functions: visibility and monitoring, optimization, prediction, simulation, collaboration, and training.

The last step of the SLR, the research agenda's definition, covers the analysis's last aspect (vom Brocke et al. 2009). Here, the *paths for further research* described by the 44 objects are synthesized. The result is a roadmap for future research activities.

4 OBSERVATIONS AND DISCUSSION

The observations of this review are manifold. This section provides them along with a brief discussion.

4.1 Review of the Search Query

The first aspect is the number of hits the SLR yields. Although an exhaustive search was aimed at and, thus, a variety of fitting databases are considered, only relatively few initial hits are found. Quality issues further decimated these hits (cf. Section 3). The fact that only a few hits are found after a comprehensive search and that these are reduced by a factor of four after a quality check indicates several possible aspects:

Specificity of the search query: The original search query may have been too general. A more precise formulation could lead to fewer but more relevant results. Often, objects had to be dismissed because they fulfilled the initial search requirements that the search terms are mentioned in the title, abstract, or keywords. Still, the publication itself did not address the industrial metaverse further. Nevertheless, an even more specific filter could limit the results even more. Therefore, we accept a higher number of irrelevant objects that must be sorted out manually.

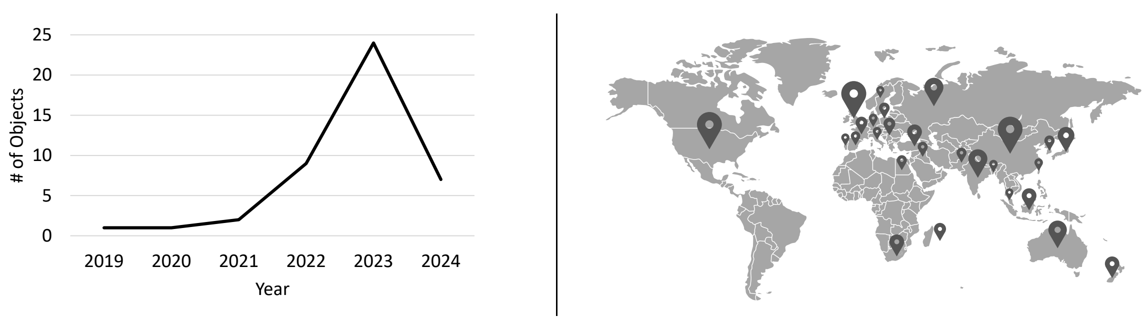
Quality filter: The quality check is aimed at relevance, rigor, and a clear relation to the topic. Thus, low-quality results, outdated information, or unverified sources are excluded, reducing the number of hits.

Niche area: The low number of overall hits (compared to a search for related concepts such as digital twins or simulation with thousands of hits) indicates that the industrial metaverse in logistics is still a niche area. Thus, a lack of data must be determined. Yet, this can have two reasons. The minor interest could be because the topic is somewhat irrelevant to the majority. Or, as in this case, the research commences. The analysis of the level of deployment further backs this hypothesis. A total of three different levels are distinguished. These are objects that describe implementations of the industrial metaverse that are still in a conceptual status or review. The second level contains objects that already describe prototype applications and actual experiments with the metaverse. Finally, the third level includes the objects that already describe the complete practical application of the metaverse. Most objects, two-thirds, belong to the first level, the conceptual one. 27% of the objects already belong to the second level and describe prototypical applications, while the remaining seven percent illustrate a productional deployment. This underlines the infancy of the topic and leads to the conclusion that the low number of objects will grow significantly.

Overall, it is essential to note that the number of hits alone is not always an indicator of the importance or quality of a topic. A thorough analysis of the available information is crucial in order to draw sound conclusions.

4.2 Review of the Objects' Yearly and Geographical Distribution

Figure 2 illustrates the yearly distribution of the objects (a)) and the origin of the objects (b)). Although the search is not limited timewise, it yields only hits from the year 2019 onwards. This aligns with the presumption that the industrial metaverse is a young concept. The number of objects grows exponentially from just one object in 2019 to 24 in 2023. As the search only contains the first two months of the year 2024, the number of objects plunges. Yet, if the growth rate of the first two months continues, this year will also see another significant increase in the number of publications. This shows the relevance of the topic. The remarkable interest reflects the increasing importance of the industrial metaverse in the logistics and supply chain sectors. Researchers and companies from these sectors see a wide range of application scenarios. As the interest continues to grow and maintain, the industrial metaverse will significantly impact the future of logistics and transportation.



a) b)

Figure 2: Objects' Yearly and Geographical Distributions.

Along with the yearly distribution, the origin of the research teams is shown in Figure 2b). The research teams in the field of the industrial metaverse in logistics have an international focus and are of a similar size in the USA, Europe, and Asia. This global distribution of research activities reflects the worldwide relevance of the industrial metaverse for the logistics industry.

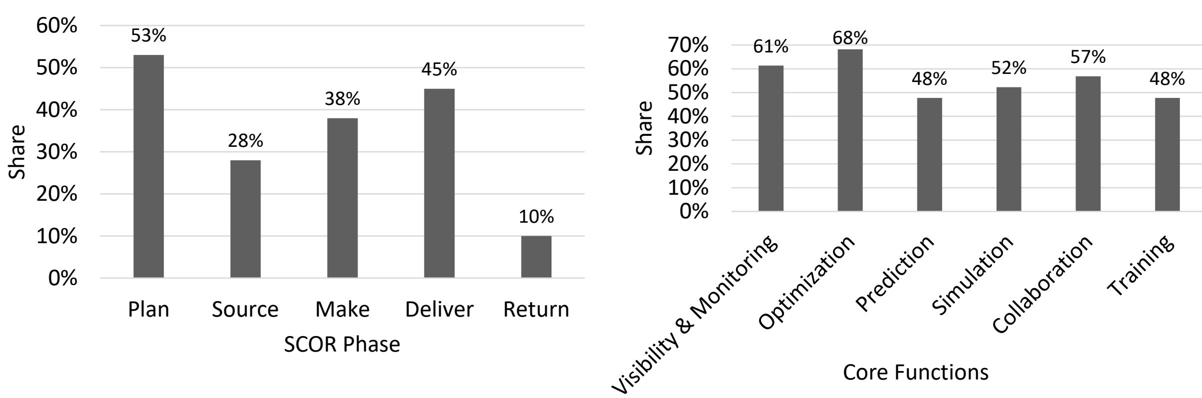
Collaboration across national borders allows for combining different perspectives, areas of expertise, and resources. This promotes innovation and accelerates progress in the field of industrial metaverse in logistics.

As diverse as the origins are, the domains in which the objects anchor the metaverse. The objects belong to one of eleven different domains. These are alphabetically: Automotive, Aviation, Commerce, Finance Sector, Food Sector, Household Supplies, Oil & Mining Industry, Production overall, Supply Chain Management overall, Warehouse Logistics, and Unspecific. A meaningful distribution is not derivable, as nearly all domains have a similar share. This shows that the industrial metaverse is equally relevant to these domains.

4.3 Core Functions along the SCOR Phases

The objects describe applying the industrial metaverse to supply chain problems or logistics. The different issues and exercises are sorted along the five SCOR phases to gain a clear structure for analysis. 19 of the 44 objects portray the application of the industrial metaverse in just one of the five SCOR phases. Thus, most objects illustrate using the metaverse in at least two and up to all five phases. Yet, there are some major differences between the quantities of objects addressing a SCOR Phase. Most often, the industrial metaverse is used in the plan phase. 53 % of the objects do so (cf. Figure 3a). The second most significant share is in the deliver phase with 45% and the make as well as the source phase following on the third and fourth place with 38% and 28% respectively. Far behind, the return phase contains the lowest number of objects, with just 10%. The objects' distribution allows us to weigh the relevance of the industrial metaverse to the five phases as of today's state.

The return phase is seen as the least important one. This is surprising as sustainability, reverse logistics, and general circular economy have gained a lot of interest. One would expect a higher share as the metaverse includes two drivers of the circular economy, the digital twin and generally simulation processes (cf. Section 2.1). In context with the higher shares of objects describing the metaverse application in the other four phases, it seems that the full potential of the metaverse in the return phase is yet to be leveraged in practice.



a) b)

Figure 3: Objects' Distribution along the SCOR Phases and Core Functions.

The high appliance in the other phases is unsurprising. The two core phases for a company where digital aidance in the form of the metaverse can contribute the most are the plan and make phase. During the source and deliver phase, the physical transport takes place, which is only mildly digitizable. Whereas planning has been highly digitized for years, many digital support tools exist while producing goods in Industry 4.0 and IoT environments. The high relevance in the fourth phase, the deliver phase, highlights the transformation of the downstream processes. These processes gain many digital services that the metaverse may support. Similar developments were identified for digital twins in the past years (cf. Lugaresi et al. 2023; van der Valk et al. 2022). Thus, a shift in the importance of the phases can be expected within the following years.

Another aspect is the distribution of the core functions. These six functions derive themselves from the purposes of SCM and the industrial metaverse (cf. Section 2). Here, the variance is less vast, and all core functions are often addressed. The least amount of objects predict the system's behaviors or train users with the metaverse. Still, nearly half of the objects do so (cf. Figure 3b). Most objects use the metaverse to optimize the system (68%). The tasks of visibility and monitoring (61%), collaboration (57%), and simulation (52%) follow suit. While some objects argue that the metaverse can predict system behavior and train users, most focus on optimizing the system and the various tasks contributing to the industrial metaverse's functionality.

Besides these core functionalities, the metaverse's further purposes in logistics are mentioned. For instance, Hussain et al. (2023) propose using the metaverse for remote diagnostics of a system, Abdulameer and Ibrahim (2023) integrate big data analyses into their metaverse, and Dong et al. (2023) suggest executing financial transactions via the metaverse.

Yet, each further functionality is only mentioned one or two times. Thus, for a meaningful analysis, the six core functions remain for the subsequent analysis step. This step matches the five SCOR phases' six core functions (cf. Figure 4). The matrix shows how many objects in a SCOR phase are used for a specific core function. For example, all objects in the source phase have used the metaverse to optimize a system. The quantity of the objects that address the SCOR phase is the foundation for calculating percentages.

	SCOR Phases				
Core Functions	Plan	Source	Make	Deliver	Return
Visibility & Monitoring	71,4%	63,6%	80,0%	61,1%	50,0%
Optimization	81,0%	100,0%	93,3%	83,3%	100,0%
Prediction	57,1%	63,6%	66,7%	66,7%	75,0%
Simulation	76,2%	63,6%	86,7%	66,7%	100,0%
Collaboration	81,0%	63,6%	86,7%	66,7%	100,0%
Training	57,1%	54,5%	86,7%	50,0%	75,0%

Figure 4: Matrix of the SCOR Phases and Core Functions.

The plan phase focuses on using the metaverse to optimize processes and systems and for collaboration within the planning team. This is not surprising insofar as optimization is a core task of planning processes and, therefore, occurs more frequently in the planning phase per se. In addition, planning processes often integrate a wide variety of organizations or departments along the way so that the collaboration effect is strongest here. The former describes Hussain et al. (2023), whereas Zhong and Zhao (2024) exemplify the latter. Fewer organizations use the metaverse to predict system elements and train their employees – only around 57% do both. Since easier-to-use tools are available for the deterministic prediction of system elements, using the metaverse would be too time-consuming. Similarly, the training of users in planning systems and processes is of secondary importance.

As already mentioned, all objects use the metaverse to optimize sourcing. The specific optimization properties are diverse (cf. Abdulameer and Ibrahim 2023; Bag et al. 2023). Surprisingly, the metaverse only monitors and visualizes source processes in two-thirds of cases. A much higher proportion would have been expected here. Around two-thirds also use the metaverse to simulate and collaborate on the sourcing process, whereas the training aspect can also be classified as low here.

The distribution within the make phase is more homogeneous. Similar to the plan phase, prediction accounts for the smallest share. Only two-thirds of the objects use the metaverse for this. Simpler tools like spreadsheets also exist in the make phase for deterministic prediction. Most objects, 93%, use the metaverse to optimize production processes. Examples are Pesca et al. (2021) and Dolgui and Ivanov (2023).

However, only slightly fewer objects also describe process simulation, collaboration between process participants, and the training of employees as core tasks. Training has the highest proportion ever in this phase. However, this is also where the expected benefits are greatest. Edwin et al. (2023), for example, suggest training employees on the handling of equipment using the metaverse.

In the next phase, the delivery phase, the benefit of training drops again, and correspondingly, few objects describe training as a core function in this phase. As in the source phase, the system optimization feature is used the most here. The proportion of monitoring is also surprisingly low.

The return phase shows a very ambivalent picture. However, a conclusive analysis is complicated due to the small number of properties. However, there are trends in the relevance of simulation and collaboration in this phase. Return processes are rarely already implemented and include many different stakeholders. Coordination and simulation of these processes are, therefore, essential. Here, too, the low importance of monitoring is surprising. Particularly in the context of hazardous goods returns, i.e., the return of car batteries from BEVs, a higher relevance would have been expected here.

The matching between the phases and the core functionalities shows tendencies for metaverse applications to have hotspots. As the metaverse is a relatively young concept, much work must be done to design applications in these relevant areas. This point is further considered in Section 5.

4.4 Architectures for the Industrial Metaverse

Nearly one-third of the objects provide applications for the industrial metaverse in logistics and outline a possible architecture. For instance, Dong et al. (2023) propose a multilayer architecture (cf. Figure 5). They start with the *Access Layer*, which connects the metaverse with the users through interfaces for different user groups. The middle is the *Application Layer*, where the various services are located. The foundation of the metaverse is the *Blockchain Layer*. Here, the calculations are performed securely and transparently.

Rosilius et al. (2023) provides another example. Here, three main entities create the metaverse. These entities are a low-code framework, Unity with further clients and interfaces, and web services. Nevertheless, the architectures are either based on existing architectural descriptions, e.g., blockchains such as in Davies et al. (2024) or are not fully mature architectures. Therefore, the need for a thorough analysis of systems' requirements and following the design of a reference architecture arises.

4.5 Connection to Simulation and Digital Twins

As mentioned in Section 2.2, simulation applications and digital twins are elementary enablers for the industrial metaverse. Therefore, a close relationship is to be expected. During the objects' analysis, attention

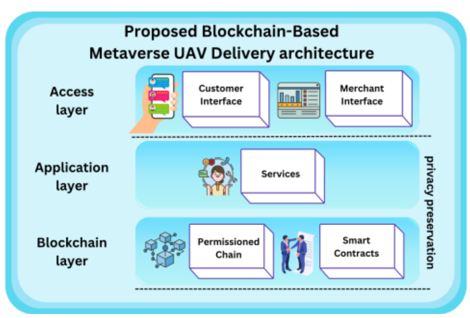


Figure 5: Proposed Metaverse Architecture by Dong et al. (2023, p. 660).

was paid to how the objects link one of the two technologies. This can already be deduced from the observations made previously for the simulation. Figure 5 shows that each phase has a high share of relation with the simulation. Overall, 58% of the objects make use of simulation applications.

Furthermore, 45% of the objects connect the metaverse with a digital twin. This fact is interesting as both concepts are young technologies. Nevertheless, they show a close connection, and their relevance to each other, which could be assumed from the preliminary literature review, can be confirmed. Over 80% of the objects using the digital twin also apply simulation. This strong relationship has also been proven once more.

5 PATHS FOR FURTHER RESEARCH

As a fifth step, the research method suggested setting a further research agenda after analyzing the objects (vom Brocke et al. 2009). To this end, the statements of the 44 objects on possible further research steps are analyzed. Not all objects formulate apparent further research efforts, but some objects express several. As a result, a total of 50 individual aspects are collected. These include, for example, additional research on the aspects of smart contracts, standardization, or the reduction of infrastructure costs for the metaverse.

These 50 individual aspects are grouped into six dimensions. These are: Business Modeling (BM), Company Strategy, and Regulations: developing new business models and corporate strategies in compliance with regulatory authorities. Standardization: creating interoperability and connectivity. Creation of the Digital World: modeling and development of digital twins. Metaverse Services: services offered by the metaverse, such as big data analytics. Data Security: security, safety, and privacy protection. Metaverse Infrastructure: for example, decentralization cost reduction services included.

Figure 6 shows the schematic representation. The most critical research path for the future is Metaverse Services. More than a quarter of all aspects belong to this area. Within this dimension, further research efforts into the automation of operations stand out above all (cf. Ostroukh et al. 2023), as well as the use of smart services for various aspects of SCM (cf. Popescu Ljungholm 2022). The second crucial research path is the Creation of the Digital World. This includes the visualization of systems, the development of digital twins (cf. Tsang et al. 2022), and the creating of user experiences in the digital world (cf. Hussain et al. 2023).

Research efforts in the areas of Metaverse Infrastructures and Standardization are mentioned with equal frequency. The former includes research into the decentralization of actors (cf. Dong et al. 2023), reduction of the costs of the technology, the inclusion of services and users, and the scaling of the metaverse to include additional actors easily (cf. Zhong and Zhao 2024). Standardization primarily concerns the creation of interoperable collaborative and connective environments so that the various actors can communicate with each other and entry barriers for participation are as low as possible (cf. Bag et al. 2023).

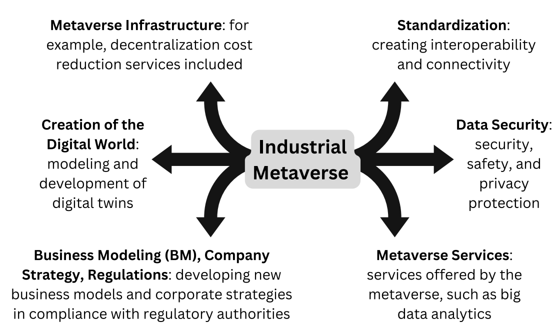


Figure 6: Future Research Paths on the Industrial Metaverse.

This is closely followed by research proposals relating to the topics of business model development and the introduction of smart contracts, taking into account the legal and ethical requirements that the meta would have to fulfill (cf. Abdulameer and Ibrahim 2023). Finally, in last place comes the topic of data security, which includes aspects of security, safety, and privacy (cf. Luo et al. 2023).

While the research shows that the application of the Industrial Metaverse is still in its infancy, it holds enormous potential for the supply chain. The decentral infrastructure of the metaverse neatly aligns with the federated nature of a supply system. Although this aspect drives costs for many digital solutions, in this case, the metaverse supports the structure and allows for fewer costs. In also includes the transparency abilities for the illustration of supply chains and offers higher resilience for a fast and secure reaction to disturbances within the supply chain.

In summary, the metaverse holds immense potential for transforming supply chains, enhancing transparency, and promoting collaboration among various actors. Researchers should focus on these critical areas to unlock the full benefits of the metaverse in supply chain management.

6 CONCLUSION

This research delves into the current theoretical knowledge about the industrial metaverse in logistics and supply chain management. Via an exhaustive SLR, a database of publications from engineering and computer sciences emerges. The database is analyzed along the SCOR framework and shows a steep climb in knowledge worldwide. Yet, the absolute majority is still groundwork on the metaverse. It is mainly used during the system's planning, while there is only low usage in the return phase. The application of the metaverse is evenly distributed between the six core functions. Nevertheless, a strong focus on optimization, simulation, collaboration, and training is noticeable. The metaverse's architecture development is still in its infancy, but fierce interrelations between industrial metaverse, simulation, and digital twins are present and, thus, influence its architecture. Lastly, the analysis shows paths for future research. Therefore, both ROs are answered.

Unfortunately, some limitations apply: the research is a snapshot of time. The work on the metaverse is undergoing development. Due to its maturity level, only a few managerial implications were derived. Still, managerial implications are the need for new business models containing services, as these are an opportunity to create a new business sector. The research provides further scientific contributions: it summarizes the knowledge and provides paths for additional research studies. It, thus, defines new research objectives for further research. Future research is the design of services provided via the metaverse, the creation of the digital world incorporating digital twins and simulation models, and the development of standards for a shared infrastructure.

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