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Barriers to the adoption of the Metaverse in digital supply chains

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Atif Saleem Butt
St Lucia Campus, The University of Queensland, Brisbane, Australia and Department of Management, School of Business, American University of Ras Al Khaimah, Ras Al Khaimah, United Arab Emirates
Mohammad Alghababsheh
Department of Business Management, School of Business, Mutah University, Alkarak, Jordan, and
Usama Awan
CREDS – Centre for Research on Digitalization and Sustainability, University of Inland, Lillehammar, Norway

Abstract

Purpose – The study explores key barriers to the adoption of the Metaverse technology in digital supply chain management (SCM) and further unveils strategies that supply chain managers can employ to overcome these barriers.

Design/methodology/approach – The study deploys a multiple case study method approach involving 30 semi-structured interviews conducted with supply chain managers from five automobile firms. These firms were in the initial phase of adopting the Metaverse technology. Interviews were the main source of data collection along with additional secondary sources such as firms' reports, media outlets, webpages and policy documents.

Findings – The results reveal seven barriers that impede the successful implementation of the Metaverse in digital SCM. These are lack of collaboration between supply chain actors, lack of commitment from top management, lack of education and awareness, timid organizational culture, financial challenges (cost of developing, integrating and maintaining technology), legal and ethical challenges (privacy issues, data storage issues, etc.) and, finally, lack of technological infrastructure and capabilities.

Research limitations/implications – The results are based on a sample size of 30 participants. Hence, they should be treated with caution and not generalizable to a broader population. Moreover, this study relies on cause-and-effect relationship to explore the phenomenon of interest.

Practical implications – The study provides several constructive guidelines to supply chain managers and member firms to overcome challenges related to the adoption of the Metaverse in digital SCM.

Originality/value – While the digital supply chain literature is enriched with studies focusing on the merits/benefits of the Metaverse, limited studies exist on the main barriers to its adoption. The study contributes to the digital supply chain literature by revealing the technological, organizational and environmental barriers of the Metaverse. The study also unveils specific properties that contribute to the emergence of these main barriers.

Keywords Technology adoption, Barriers, Metaverse, Industry 4.0, Supply chain management, Digital twins

Paper type Research paper

1. Introduction

The Metaverse, a real-time, immersive virtual environment that enables people to interact with a sense of presence using technologies like augmented reality (AR) (Ball, 2022), has gained significant attention in recent years. This digital ecosystem has the potential to transform various industries, including social interactions, entertainment, education, healthcare and business (Dolgui and Ivanov, 2023, 2024; Dwivedi *et al.*, 2022). In the business world, the

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Metaverse offers new opportunities for supply chain management (SCM) (Bag *et al.*, 2023; Dolgui and Ivanov, 2023). Modern supply chains are increasingly global, dynamic and complex (Ali *et al.*, 2021), making them vulnerable to inefficiencies, poor visibility and disruptions.

Creating virtual replicas of physical assets and processes within supply chains allows for real-time monitoring, predictive maintenance and scenario planning. In addition, the Metaverse has the potential to improve operational efficiency and decision-making (Chen *et al.*, 2023; Queiroz *et al.*, 2023; Riaz *et al.*, 2024). On the other hand, technologies like virtual reality (VR) within supply chains can facilitate remote collaboration among stakeholders, enable virtual site visits, training and design reviews, which can lead to faster innovation cycles and reduced time-to-market (Bag *et al.*, 2023). Finally, the implementation of Blockchain within the Metaverse can ensure secure and transparent tracking of goods and transactions, fostering trust and compliance throughout the supply chain (Chen *et al.*, 2023). However, despite these potential benefits, research on the adoption of the Metaverse in SCM remains limited.

While most studies focus on the benefits of the Metaverse for SCM, little attention has been given to the challenges and barriers hindering its adoption. Understanding these obstacles is crucial both from theoretical and practical perspectives. From a practical standpoint, identifying adoption barriers enables firms to develop targeted strategies for overcoming them, ensuring smoother integration and maximizing benefits (Rathore, 2023). Theoretically, investigating these barriers helps build conceptual frameworks that guide future research in this emerging area. As Bag *et al.* (2023) emphasize, overcoming such barriers is key to realizing the Metaverse's full potential in SCM—enhancing collaboration, improving connectivity and reducing costs, which account for over 70% of total supply chain expenses. Despite its significance, studies on the key obstacles to implementing the Metaverse in SCM are scarce, leaving a critical research gap in digital supply chains. This study addresses this gap by pursuing two main objectives: (1) identifying the primary barriers to Metaverse adoption in SCM and (2) developing actionable strategies for firms to overcome these barriers. Based on an initial review of the literature, the study is guided by the following research question:

RQ1. What are the main barriers to the adoption of the Metaverse in SCM?

To address this question, the study adopts an exploratory qualitative approach. 30 semi-structured interviews were conducted with supply chain managers in the process of implementing the Metaverse technology in a country that is actively building its Metaverse ecosystem to become one of the main players in the Metaverse in the world. The collected data were analyzed using three coding methods (i.e. open coding, axial coding and selective coding). The study found seven barriers to the adoption of the Metaverse in SCM, representing organizational, technological and environmental aspects. The trustworthiness of these findings were evaluated in terms of credibility, transferability, dependability and conformity.

The study contributes to the SCM literature in the following ways. First, it presents seven barriers to integrating the Metaverse into SCM. Notable, the study develops a nuanced approach by highlighting how some of the barriers in this study are unique from other barriers as discussed in industry 4.0 literature. Thus, the study provides valuable insights into the overall digital transformation in SCM. Second, the study contributes to practice. It does so by providing some constructive guidelines to managers and firms on overcoming these obstacles. Firms can implement these guidelines to overcome the obstacles noted in this study and have a smooth transition to the Metaverse technology with minimum interruption to their business operations.

The remainder of the paper is structured as follows: Section 2.1 discusses the basic concept of the Metaverse. Section 2.2 critiques current literature on Industry 4.0, including AR and digital twins as part of the Metaverse. Section 2.3 articulates the drivers and performance objectives of the Metaverse in SCM. Section 3.1 focuses on sampling and data collection. Section 3.2 extrapolates data coding and analysis. Section 3.3 discusses research trustworthiness. Section 4 discusses results thematically, including raw quotes. Section 5 articulates the contributions of this study to theory and practice. Section 6 highlights the limitations of the study and future research directions. Section 7 concludes the paper.

2. Literature review

2.1 Foundations of the metaverse in SCM

The Metaverse is a compound term consisting of “meta” and “verse,” symbolizing “transcendence” and “the universe,” respectively. Together, they signify “a world beyond the real world.” The term was first introduced by Neal Stephenson in his novel *Snow Crash* (Joshua, 2017; Sparkes, 2021). However, it was not until recently that the term gained widespread recognition, particularly after Facebook rebranded as “Meta.” Over time, this concept has evolved to encompass a wide range of immersive technologies and experiences. Today, the Metaverse refers to an interactive VR environment where users can seamlessly engage with both other users and digital elements (Choi *et al.*, 2023; Belk *et al.*, 2022). Science fiction has popularized this idea, depicting it as a futuristic society where the boundary between the real and virtual worlds blurs. However, the concept is still evolving and defined in multiple ways. A comprehensive definition is provided by Ball (2022):

> A massively scaled and interoperable network of real-time rendered 3D virtual worlds that can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments.

Recent advancements in technology and increasing business investments have fueled interest in the Metaverse, with predictions that it will revolutionize business operations and industry frameworks (Peukert *et al.*, 2022). A significant milestone in its development has been the emergence of massively multiplayer online role-playing games (MMORPGs) like *World of Warcraft* and *Second Life* (Wiederhold, 2022). These platforms have demonstrated the potential of virtual environments for social interaction, commerce and digital asset exchange.

The Metaverse literature classifies the foundation of this notion within the context of SCM into three main taxonomies. The first one is, conceptual foundation, which encompasses the term’s definition, its technological description and a unique theoretical conceptualization of the idea. Second, one is an application where practical demonstrations within supply chain contexts (e.g. logistics and transportation), particularly through digital twins and VR environments (augmented and mixed reality), are undertaken. The third one sought to highlight the benefits (applications) of the implementation of the Metaverse technology in the context of SCM. However, the barriers that hinder the implementation of the Metaverse technology in SCM have received limited empirical attention. Table 1 presents the taxonomies of the Foundations of the Metaverse in supply chains.

Table 1. Metaverse taxonomies in supply chains

Taxonomy	Description	Supporting literature/Studies
Conceptual Foundation of the Metaverse	Focus on the definition of the Metaverse as well as the theoretical understanding of the Metaverse, including VR, blockchain and digital twins	Ball (2022), Choi *et al.* (2023), Belk *et al.* (2022)
Application of the Metaverse	Exhibiting the application of the Metaverse in a supply chain management setting in the form of digital twins, smart warehousing and remote collaboration	Wiederhold (2022), Dwivedi *et al.* (2022)
Benefits of the Metaverse	Reveals the benefits of the Metaverse adoption in the supply chain domain. Further discuss how the Metaverse brings transparency in the supply chain processes, including reduction in lead times and enhanced resilience/agility	Trivedi and Negi (2023), Bag *et al.* (2023), Dubey *et al.* (2023)

Source(s): Authors’ own work

2.2 Industry 4.0, digital twins and the metaverse

The Fourth Industrial Revolution (Industry 4.0) is characterized by the integration of digital and physical realms to form cohesive cyber-physical systems. The literature classifies Industry 4.0 literature into two main domains: Technological centric and process centric. The technological-centric literature focuses on current and emerging trends in Digital Twins and IoT, etc. for enhancing real-time analytics and visualization. While process-centric focuses on the application of these technologies within different segments (manufacturing, logistics, etc.) of SCM. Unlike previous industrial revolutions primarily focused on enhancing productivity, Industry 4.0 leverages technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) to enhance automation, monitoring and control capabilities (Hasan *et al.*, 2022). Central to this transformation is the concept of Cyber-Physical Systems (CPS), which seamlessly integrate computational and physical processes (Künz *et al.*, 2022).

A core component of Industry 4.0 is the Digital Twin—a virtual representation of a physical system that enables real-time monitoring and decision-making. Systematic literature reviews have examined Digital Twins within Industry 4.0 for smart manufacturing, classifying their applications across various facets such as product design, process optimization and predictive maintenance (Cinat *et al.*, 2020). Stavropoulos and Mourtzis (2022) emphasize that Digital Twins enable industries to promptly identify physical issues, enhance predictive modeling accuracy and refine product development processes.

Furthermore, Zhu *et al.* (2019) argue that IoT-driven Digital Twins facilitate mass customization while maintaining production efficiency. AR enhances the visualization and interaction with Digital Twin data by seamlessly integrating digital elements into physical environments. Additionally, the development of Digital Twin reference architectures and Digital Twin as a Service (DTaaS) has demonstrated significant advantages such as optimized maintenance scheduling, real-time monitoring and predictive functionalities (Aheleroff *et al.*, 2021). These findings underscore the connection between Digital Twin service capabilities and their impact on industry-wide adoption.

2.3 Applications and benefits of the metaverse in SCM

The Metaverse is receiving increasing research attention in the context of SCM, particularly in improving supply chain visibility and efficiency. Particularly, the literature discusses the benefits and its application within three broad areas within SCM literature, including transparency and visibility, collaboration and innovation and finally efficiency and optimization. To begin with, the Metaverse applications enhance transparency by providing real-time digital representations of goods, production processes and logistics (Ooi *et al.*, 2023). Sadeghi *et al.* (2025) and Zanman *et al.* (2025) note that the Metaverse brings transparency into supply chains by supporting stakeholders' sustainability assessment procedures. However, studies on Metaverse adoption based on the frameworks of Technology Acceptance Model (TAM) and Technology–Organizational–Environment (TOE) show that perceived infrastructure readiness and data-security concerns significantly influence managers' willingness to deploy immersive visibility tools (Bag *et al.*, 2023).

Additionally, the Metaverse environments foster collaboration across the supply chain, enhancing overall efficiency (Trivedi and Negi, 2023). The integration of virtual tools and 3D visualization accelerates innovation, enables mass customization and improves stakeholder accountability (Dubey *et al.*, 2023). The Metaverse also facilitates digital product replication, optimizing resource allocation and enabling alternative production scenarios (Chen *et al.*, 2023; Shardeo *et al.*, 2024). Furthermore, collaborative virtual spaces improve supply chain communication, allowing firms to engage in joint product development and rapid feedback exchange (Cui *et al.*, 2022). This, in turn, reduces development cycles and associated costs while improving responsiveness to market changes (Wan *et al.*, 2023a, b). Moving on, early adoption research finds that relative advantage and trialability accelerate Metaverse-based collaboration platforms, but complexity and lack of user training often slow wider diffusion options (Vyas *et al*., 2025).In addition, Vyas *et al*. (2025) explore the benefits attributed to the Metaverse in supply chains and found that the Metaverse technology brings more efficiency to supply chain ecosystems.

In warehouse management, the Metaverse enhances operational efficiency by enabling dynamic space modeling and slotting optimization (Queiroz *et al*., 2023; Mancuso *et al*., 2023). These advancements are particularly valuable in the context of micro-fulfillment centers, where space constraints demand innovative solutions (Trivedi and Negi, 2023). On the other hand, Khan *et al*. (2025) noted that the Metaverse makes the supply chain more robust and benefits warehouse management operations, particularly in small and medium-sized enterprises. Moreover, understanding global supply networks remains a challenge, yet the Metaverse provides greater transparency by visualizing raw material sources, production sites and supplier relationships (Bag *et al*., 2023). In logistics, the Metaverse streamlines transportation planning and inventory management. Wan *et al.* (2023a, b) argue that logistics firms can achieve reduced lead times and lower shipment costs through Metaverse-driven simulations and predictive analytics. In addition, technology adoption studies within the small and medium enterprise context, specifically drawing on the unified theory of acceptance and use of technology (UTAUT) model, argue that performance expectancy and facilitating are critical determinants of Metaverse-based optimization uptake (Khan *et al*., 2025; Zhang *et al.*, 2024).

2.4 Technology–Organization–Environment (TOE) framework

The TOE framework, introduced by Tornatzky and Fleischer (1990), provides a comprehensive lens for analyzing the adoption and diffusion of emerging technological innovations within organizations. This framework has been widely employed in information systems and digital transformation research, offering a structured and overarching approach to understanding the multifaceted factors influencing technology adoption. It considers three key dimensions: technological, organizational and environmental. Technological context encompasses factors such as interoperability, infrastructure requirements, security concerns and the maturity of Metaverse-related technologies (AR, VR and blockchain). Firms' readiness in digital twins, IoT and AI also influences adoption feasibility (Dwivedi *et al*., 2022). On the other hand, organizational context covers firm size, management support, resource availability and employee adaptability. Large firms with strong digital infrastructures are better positioned for adoption, while SMEs may face financial and cultural barriers (Trivedi and Negi, 2023). Finally, the environmental dimension of the TOE framework includes external influences like regulatory policies, competitive pressures, industry standards and customer expectations. Collaboration among supply chain stakeholders also plays a crucial role in the Metaverse diffusion (Bag *et al*., 2023).

The TOE framework is particularly relevant for investigating the barriers to Metaverse adoption in digital supply chains due to its holistic approach to technology adoption. In comparison to other technology adoption models such as the Diffusion of Innovation theory (Rogers and Leuschner, 2004), which emphasizes stages of individual-level adoption and adopter characteristics or the TAM (Davis, 1993), which centers on perceived usefulness and ease of use, TOE captures a broader organizational and environmental context that is critical in enterprise-level decisions. First, Metaverse adoption in SCM involves not only technical considerations but also strategic and environmental factors. The technological dimension helps identify technical constraints such as infrastructure gaps, cybersecurity risks and integration challenges with existing digital supply chain systems (Peukert *et al*., 2022). The organizational dimension highlights internal resistance, financial constraints and workforce adaptability, which are critical barriers to implementation (Choi *et al*., 2023). The environmental dimension further contextualizes the adoption process by examining industry regulations, competitive dynamics and stakeholder collaborations, all of which are essential in understanding the external pressures influencing firms (Dubey *et al*., 2023).

However, in contrast to the TOE model, the TAM and Diffusion of Innovation theory attempt to inadequately address external institutional or regulatory pressures, TOE emphasizes the role of policy frameworks, market competition and supply chain ecosystems, making it particularly suited for analyzing emerging technologies like the Metaverse within complex supply networks. Furthermore, the TOE framework enables a systematic examination of barriers at multiple levels, facilitating a structured exploration of adoption inhibitors and enablers. By categorizing challenges across technological, organizational and environmental domains, this study can provide nuanced insights into the interplay between internal capabilities and external contingencies that hinder Metaverse integration in digital supply chains (Mancuso *et al*., 2023). Finally, given the nascent stage of Metaverse applications in SCM, empirical research on adoption barriers remains scarce (Shardeo *et al*., 2024). Applying the TOE framework allows this study to contribute to the existing literature by offering a multidimensional perspective on the constraints that organizations face, thereby informing future strategic and policy recommendations for facilitating the Metaverse adoption.

3. Research design

Consistent with our research aim of exploring the barriers to the adoption of the Metaverse in SCM, this paper relies on a multiple case study methodology, which involves "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2009, p. 18). This methodological alternative is deemed suitable for an under-explored research topic (Eisenhardt, 1989) such as the Metaverse in SCM. It allows scholars to build a nuanced understanding of a complicated phenomenon that can extend experience or add strength to current knowledge (Welch *et al.*, 2022). The adoption of the Metaverse in SCM is a complex phenomenon as it involves different stakeholders and technological, organizational and environmental aspects.

A multiple-case study method approach was used rather than a single case study, as it provides compelling evidence, achieves replication, strengthens the emerging constructs and reveals a better pattern of relations among constructs (Stuart *et al.*, 2002). Given the qualitative nature of this study, theoretical sampling was used to enhance the validity, reliability and breadth of the findings (Guba and Lincoln, 1994). In doing so, a preliminary assessment of each case study was conducted through secondary documentation, ensuring the relevance of the case study, positioning within the supply chain industry and strategic orientation. After the identification of cases, the knowledgeable interview participants (managers) were invited to participate in the study through emails. Figure 1 presents detailed steps ranging from research design to the trustworthiness of the findings.

3.1 Sampling and data collection

The study's population consists of five UAE-based automobile firms that receive the Metaverse services from a tech-based company. These customers (manufacturers of automobiles) determine whether and when the Metaverse will be adopted according to their business demand, and they are the ultimate users of the Metaverse and the problems associated with its implementation. Additionally, these automobile clients have been adopting the Metaverse in different ways, such as design process, online purchasing, smart manufacturing, in-car entertainment and virtual driving experience. Overall, 30 semi-structured interviews were undertaken with supply chain managers from these five automobile firms. To ensure consistency, all the interviews were conducted by the same researchers, who followed the same protocol for each session. These managers held moderate to high experience in their respective fields. Further details are provided in Table 2.

Before conducting the main interviews, a pilot study was undertaken with seven participants to refine the interview protocol, ensuring the clarity and relevance of the interview questions. This is particularly important as some supply chain professionals may not be very familiar with Metaverse-specific jargon (e.g. AR, immersive environments). To address

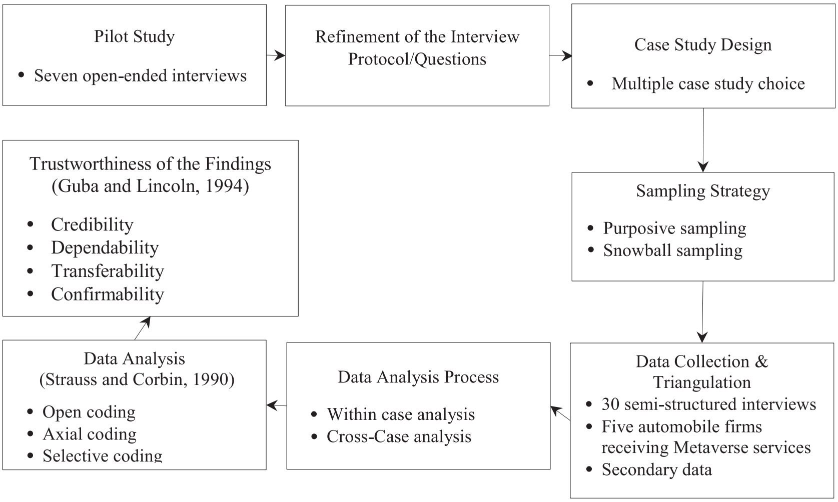

Figure 1. Multiple case study research design (Source: Authors' own work)

Table 2. Study sample

Automobile manufacturers	Respondent codes	Time spent in a prescribed role	Demographics of interviewees	Firm's headquarters	Number of branches worldwide
Case Study I	R1, R2, R3, R4,R5, R6	Moderate to high	70% Expats 30% Local	United States of America	30
Case Study II	R7, R8, R9, R0, R11, R12, R13, R14	Average to medium	90% Expats 10% Local	United Kingdom	35
Case Study III	R15, R16, R17, R18, R19	Moderate to high	65% Local 35% Local	Germany	42
Case Study IV	R20, R21, R22, R23, R24	Moderate to high	80% Expats 20% Local	United States of America	35
Case Study V	R25, R26, R27, R28, R29, R30	Moderate to high	60% Local 40% Local	China	28

Source(s): Authors' work

potential data bias, the study employed a combination of purposive and snowball sampling techniques. Initially, 20 knowledgeable respondents (supply chain managers) were identified through purposive sampling. These participants were then asked to recommend other suitable respondents, resulting in an additional 10 participants. This approach ensured a diverse sample of 30 respondents with moderate to high experience in their respective fields. The snowball sampling technique was particularly useful in accessing hard-to-reach participants with specific knowledge of the Metaverse. The interviews were conducted over five months. Each interview lasted between 60 and 120 min and was transcribed and recorded verbatim. The interview protocol is provided in Appendix A. After conducting 30 interviews, no new themes (challenges of the adoption of the Metaverse in SCM) emerged, indicating data saturation (Fusch and Ness, 2015). Consequently, we concluded that the 30 interviews would be satisfactory for data collection purposes. To ensure that we have reached data saturation and to triangulate our findings, we accessed and analyzed relevant information from firm policy documents, websites and blogs (Creswell, 2014; Yin, 2009). These data were used to cross-validate the interview findings and provide additional context.

To confirm saturation, a second phase of interviews was conducted with 10 participants (R1, R2, R7, R9, R16, R19, R20, R25, R27 and R30). These interviews focused on validating the findings and addressing any discrepancies between the primary and secondary data. Moreover, the interview guide was developed in two steps. First, we referred to the broader literature on the Metaverse and the literature on the Metaverse in SCM to determine the interview questions that other studies might have asked for. Second, we conducted a few brainstorming sessions to assess and review the questions we had initially developed based on the first step. Specifically, we wrote down the initial questions and then discarded any questions that appeared redundant or irrelevant to the adoption of the Metaverse in SCM. Some new questions were constructed at this step to fit the case study method analysis. The final interview protocol (see Appendix A) included open-ended questions to allow for rich, detailed responses.

3.2 Data analysis

We proceeded with the within-case study analysis. This step ensured that each case was understood in its unique context before cross-case comparisons were made. After the within-case analysis, cross-case comparisons were made to identify common patterns and themes. This step involved synthesizing the findings from individual cases to develop a comprehensive understanding of the barriers to Metaverse adoption in SCM. To begin the within-case analysis, analysts first examined all of the transcripts and documentation pertaining to each single case. Second, we typed down a description of each instance (Yin, 2009) and transferred each case to Eisenhardt's case database (1989). Third, we scrutinized the transcripts for again before using Strauss and Corbin's (1990) coding paradigm, which puts forward three options for data coding, namely open coding, axial coding and selective coding. Similarly, all interviews were examined thoroughly. We broke down the data into different concepts, incidences and occurrences through open coding (Glasser and Strauss, 1967). We then assigned them a name or a code to symbolize them. To ensure consistency and reduce coder bias, the NVIVO software was used to facilitate the coding process. The software also facilitated intercoder reliability checks, which achieved a 90% agreement rate between analysts.

The coding process in this study was conducted in three iterative phases: open coding, axial coding and selective coding, following the approach proposed by Strauss and Corbin (1990). This systematic approach ensured that the analysis remained grounded in the data while allowing for the emergence of significant themes and categories related to the barriers to the adoption of the Metaverse in SCM. Each phase of the coding process is elaborated below:

(1) Open Coding: Fragmenting and Conceptualizing the Data

Open coding was the initial phase of the analysis, aimed at breaking down the data into discrete incidents, ideas or concepts. During this phase, the research team independently examined the raw data (e.g. interview transcripts, documents and observations) line by line to identify key ideas, actions or events. Each incident or idea was assigned a descriptive label or "code" that captured its essence. Given the interpretive nature of qualitative research, coding differences occasionally emerged between researchers. To maintain objectivity and ensure consistency, the team examined each other's theoretical memos—written reflections that documented the rationale behind specific codes and classifications. These memos provided insight into how each researcher interpreted the data, allowing the team to reconcile differences through discussion and consensus. This process ensured that the coding remained grounded in the data and minimized researcher bias.

By the end of the open coding phase, the data had been fragmented into numerous initial codes, which were then grouped into broader categories based on their conceptual similarities. These categories represented the preliminary themes emerging from the data, such as "lack of collaboration," "financial challenges," and "technological limitations."

(2) Axial Coding: Reorganizing and Connecting Categories

Once significant categories emerged from open coding, the research team employed axial coding to reorganize the fragmented data and explore the relationships between categories. Axial coding is a process of reassembling data in new ways by identifying connections between categories and subcategories. During this phase, the team focused on identifying the properties and dimensions of each category. For example, the category "financial challenges" was further broken down into subcategories such as "cost of technology development," "cost of employee training," and "cost of technology maintenance." This process allowed the team to delve deeper into the nuances of each theme. Axial coding also involved exploring how categories related to or cross-cut one another. This step was critical for understanding the interplay between different factors and for developing a more cohesive theoretical framework. By the end of this phase, the team had developed a more structured understanding of the data, with clear relationships between categories and subcategories. This laid the foundation for the final phase of coding.

(3) Selective Coding: Focusing on Core Variables

The final phase of the coding process was selective coding, which involved narrowing the focus to the core variables of interest—specifically, the barriers to the adoption of the Metaverse in SCM. During selective coding, the team concentrated only on the categories and subcategories that were directly relevant to the research question. This involved revisiting the data to ensure that all instances of these core variables had been thoroughly analyzed and that their relationships had been fully explored. The team examined how the core categories (e.g. "lack of collaboration," "stakeholder reluctance," and "technological limitations") were associated with one another and how they collectively contributed to the barriers to Metaverse adoption. By the end of this phase, the team had identified seven key barriers to Metaverse adoption in SCM, each supported by empirical evidence and clearly linked to the broader theoretical framework. These findings were then used to develop the study's conclusions and implications.

3.3 Evaluation of the findings

To ensure the trustworthiness of the findings, the study adopted the following measures proposed by Guba and Lincoln (1994) as noted in Table 3.

(1) Credibility: Participants were invited to review the interview transcripts to ensure accuracy and eliminate false data. This member-checking process enhanced the credibility of the findings.

Table 3. Criteria to ensure trustworthiness of research findings

Measure	Main objectives	Requirements met
Credibility	To ensure that findings are the true representations	Interviewed respondents from different firms; data triangulated through secondary means
Transferability	Findings can be transferred from one context to another	Used multiple case studies to ensure that findings can be transferred to other contexts
Dependability	Results would remain the same if the sample is repeated	Strauss and Corbin (1990)'s coding paradigm used: Open, axial and selective coding; Raw quotes provided Coding process facilitated through NVIVO
Confirmability	Findings emerge from the data through respondents' interpretation	Data collected from respondents with expertise on the management of supply chain operations

Source(s): Authors' work

(2) Transferability: The study involved participants from different roles, experiences, regions and organizations within the automobile industry. This diversity enhanced the transferability of the findings to other contexts.

(3) Dependability: A group of independent researchers was asked to code the same transcript, achieving a 90% inter-coder reliability rate. This step ensured the dependability of the coding process.

(4) Conformity: Direct quotations from participants were used to support the findings, and routine data reviews were conducted to prevent judgmental bias. This approach ensured the confirmability of the results.

4. Results and analysis

Results unveiled seven challenges (themes) to implement the Metaverse technology in SCM as per respondents' narratives. These themes permeated throughout the discussion with respondents. Particularly, respondents pointed out to lack of collaboration among SC actors, lack of commitment from top management, timid organizational culture (i.e. centralized decision-making), lack of awareness and education, financial barriers (i.e. cost of developing, integrating and implementing technology), legal and ethical barriers (such as privacy issues, data storage issues and intellectual property rights). Each of these themes, along with the raw findings are presented in Sections 4.1–4.7. See Figure 2 for detailed themes and corresponding sub-themes.

4.1 Lack of collaboration between supply chain members

Many respondents narrated that lack of collaboration between supply chain member firms is one of the most common reasons that they fail to implement the Metaverse in this domain. The

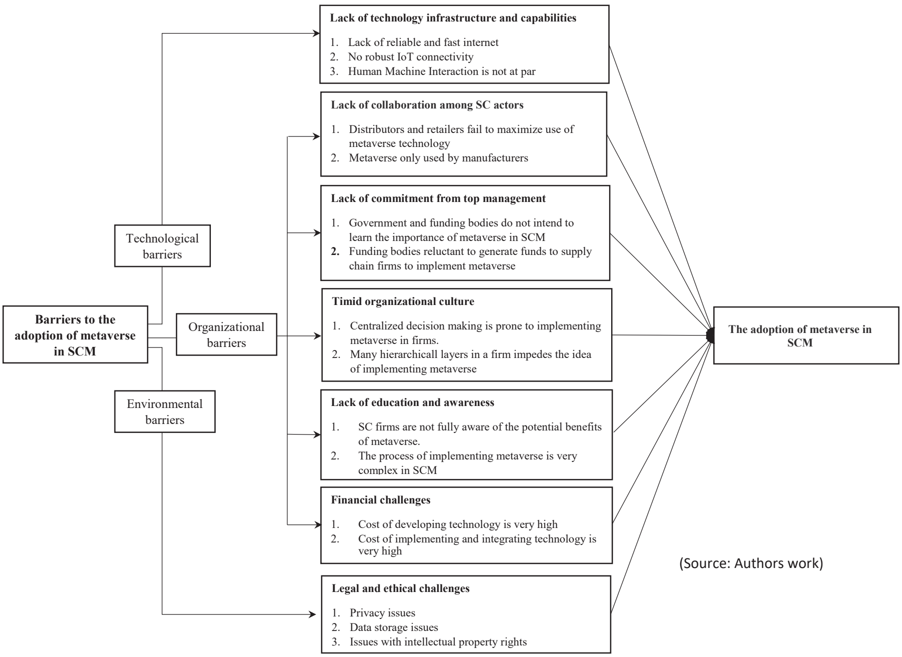

Figure 2. Pictorial model of the barriers to the adoption of Metaverse in SCM (Source: Authors' own work)

Metaverse is built on the idea of interoperability – the ability of various virtual world platforms to interact with each other. Achieving interoperability between various platforms in the Metaverse in the context of SCM is a complex task without the collaboration of the supply chain actors. Respondents, thoroughly, argued that entities within the supply chain need to establish a long-term commitment to working together. Furthermore, such commitment extends beyond traditional supply chain members and includes customers, retailers, wholesalers, suppliers, suppliers of suppliers and manufacturers. This will ensure the timely and effective flow of goods. A quote below testifies to this:

> We are yet unable to integrate the Metaverse technology in our sphere due to lack of collaboration. Firms are not willing to work together and understand how the Metaverse might really revolutionise the traditional supply chains. This is concerning (R1)

Further discussion with respondents revealed that there is, somehow, a very limited execution of the Metaverse technology in the supply chain – few member firms. He stated that the Metaverse is, so far, only making an impact in the manufacturing sector, particularly in the areas of product design. Moreover, some warehouses as well as transportation companies are now exacerbating Metaverse technology to streamline their operations. In addition, this Metaverse comes with a huge potential and can make a significant impact. However, its fullest potential cannot be realized due to a lack of collaboration between firms. Consider the quote below:

> The Metaverse has a significant impact but its potential in the supply chain cannot be fully materialized as firms are not willing to sit together and discuss how the Metaverse can change the way business operations work. The lack of collaboration between firms to realize Metaverse creates mistakes during the design process, and further put on substantial delays when suppliers do not create a virtual model with their manufacturers (R8).

More respondents' stories provided support to the above findings. They said that distribution channels are perhaps the weakest link when it comes to working with other supply chain member firms to implement the Metaverse technology in the supply chain. They stated that there lies a huge potential for the execution of AR for shipping and transporting goods, but distributors and retailers have failed to work together to maximize its use.

The failure of retailers and distributors to collaborate to maximise the use of AR for shipping locally and internationally is adversely affecting the end-consumer market. This inability to collaborate negatively impacts the utilization of the Metaverse technology.

4.2 Lack of commitment from top management

A successful implementation of technology in any firm heavily depends on its acceptance by various stakeholders in the supply chain, particularly at the senior level and progress towards the implementation of the Metaverse may be hindered by the support of upper management and cross-functional cooperations. Discussion with respondents further revealed a lack of commitment as another potential barrier to implementing the Metaverse technology in supply chains. These respondents stressed that external entities such as government and funding bodies do not actually have a drive to understand and learn how the Metaverse may revolutionise the supply chains in the short and long run. Moreover, their focus is on dealing with other issues (taxation, infrastructure, etc.) instead of fully materialising the potential of the Metaverse in the supply chain. Respondents stated that the stakeholders are not showing any intent to improve the efficiency as well as effectiveness of the supply chain networks. This is because they are not committed to using the Metaverse in the supply chain.

> Our stakeholders are just simply not ready to implement the Metaverse in our day to day running of business. I believe they are simply not interested in learning new things, and given the fact that they are not aware of how new technologies can streamline business operations. It is also because they are just focusing on other things as a top priority or do not wish to put too many resources at their disposal to guarantee the implementation of new technologies (R21).

Many other respondents concurred with the above story. They stated that there is no support from any stakeholders, whatsoever, to implement the Metaverse technology. Respondents argued that they just a different opinions and attitudes whenever we aim to discuss the idea of executing the Metaverse in the supply chain. Their behavior just makes us hard to measure their commitment to implement the Metaverse. They further argued that their support is essential for the successful implementation of the Metaverse in supply chains.

> They are just not interested in discussing the idea of the Metaverse. Not sure what is holding them back. We don't see any degree of involvement from them in the implementation of the Metaverse in SCM as well as any support and participation in the implementation process of the Metaverse technology. Ironically, we cannot really integrate the Metaverse technology in supply chains without their support. They are our initial guarantor of resources (R11).

4.3 Timid organizational culture

The Metaverse is successfully implemented when creativity and experimentation are encouraged and rapidly practiced in firms. Unfortunately, supply chain firms are not always prepared to opt for novel approaches due to issues with knowledge sharing and diversity and flexibility, which hinders the deployment of the Metaverse. Many respondents correlated organizational culture to the acceptability of the Metaverse technology. In other words, they stated that the type of organisational culture has a strong influence in deciding whether the Metaverse technology is beneficial or not. For instance, four respondents argued that if an organizational culture is flatter in nature, complemented with decentralized decision-making, than they are more likely to implement the Metaverse technology. Moreover, some top managers have a mindset or willingness to take on chances and risks with new things. Such traits oblige them to opt for new technologies and understand their benefits. The quote below provides support for this statement.

> Well, what I have seen that adopting a Metaverse technology in our line of work requires a determination or at least an intention to accept that a dynamic organisational culture is vital for success. If a firm's culture is risk-averse, make decision through consultation and reluctant to take chances then such technologies are really not designed from them (R17).

Further discussion with respondents revealed similar stories. They narrated how an organisational culture can be pivotal to implementing the Metaverse technology or vice versa. They further articulated that organisational culture is a part of firm's comprehensive strategy for the adoption of any new technology and not just the Metaverse for supply chains. They pinpointed that, sadly, many firms are yet, unable to understand the importance of new technology, or, do not have sufficient resources at their disposal. On the other hand, some firms do not plan well and fail to execute that plan. These traits can have a significant impact on the organizational culture and failure to merge these traits means they can potentially fail to use the Metaverse technology in supply chains.

> Many member firms that we work with do not have a full understanding of what it means to moving onto the Metaverse. I am not sure what's the cause behind. It might be as that they lack enough resources yet or do not plan or execute that plan properly. Unfortunately, failing to integrate these traits means failure of the use of the Metaverse in our business. The execution of the Metaverse is fraught by traditional organisational culture (R24).

4.4 Lack of awareness and education

Many respondents narrated that it is essential for each entity in a supply chain to accept and further apply the Metaverse technology in the supply chain. Otherwise, firms will not be able to make the best out of its true potential. Respondents stated that onerous remains on customers, distributors, retailers, wholesalers, distributors, suppliers and manufacturers to accept its utility. If any entity does not show willingness or desire to use the Metaverse, the supply chain, as a whole one entity's ability would be constrained. A quote below testifies to this:

> The Metaverse should be accepted as a whole. What I'm saying is its partial acceptance between members firms is not so much uselful. If no one adopts or show desire to use the Metaverse technology, then I believe network's ability to spread would remain limited (R19).

Further discussion with the respondents unveiled that many factors come into play when using the Metaverse technology. They further stated that the management of data, logistics and civil infrastructure are all linked to the application of the Metaverse technology in the supply chain. Unfortunately, if the involved parties believe that the application of the Metaverse is too complex, they may not opt for it, which may adversely affect the diffusion into the supply network. These respondents argued that the Metaverse can contribute to several areas of our business such as sustainability, transparency and more robust business operations. However, many firms, are not yet, fully aware of the potential benefits of the Metaverse and, are, therefore, reluctant to adopt or use this technology. Consider the quote below.

> I believe that none of the firms that we work with are ready to adopt the Metaverse as they do not know the huge benefits that Metaverse can bring in. They are just not motivated. Not at all! They don't realize the benefits that Metaverse has in for us. We can work on greenhouse gas emissions, bring in more transparent approach to track the products (R27).

Four more respondents also reported the issue of diffusion is another factor related to the acceptability of the Metaverse technology.

> Being unaware of the positives of the Metaverse create a poor diffusion system. What I am saying is that poor an implementation of the Metaverse has failed due to a very poor diffusion of supply chain network. And I reckon this is one of the major factors (R5).

4.5 Financial challenges

The development of a Metaverse is usually an expensive undertaking considering the scope of the project, the type of technology used and the time required to complete it. As the supply chain is a system of complex networks, implementing the Metaverse comes with huge costs. This is even true for manufacturing firms, where costs to implement is a factor that hinders the adoption of a Metaverse in the supply chain. Interestingly, our discussion with respondents unveiled that implementing the Metaverse technology potentially comes with a huge cost. Building the Metaverse for SCM involves considerable costs, including the development and maintenance of virtual environments, integration with existing systems and capability development (e.g. training) and implementing robust cybersecurity solutions to protect user data and prevent breaches. They narrated that implementing this technology is an expensive undertaking and requires continuous investment and long-term commitment. Moreover, firms continue to consider (and do not take any firm action) the financial implications associated with it before investing in it.

For instance, a discussion with five respondents stated that the first step is, perhaps, the most challenging one. That is, considering the cost of developing the technology. They argued that developing such technology requires access to extensive funds, which top management is usually reluctant to release. They further argued that firms within the supply chain need access to more resources to build a Metaverse. This ultimately means that they have to rely on an external party to purchase this technology, which comes with a huge out-of-pocket expense.

> Well, the first and foremost challenge is to consider the cost of developing this cutting edge technology. Unfortunately, we are not resourceful enough to develop this technology on own, and have to purchase the technology from third party vendors. They are currently quoting us substantially higher price. I proposed this quote to the internal stakeholders but it seems they believe that the purchase price is very high (R3).

Respondents stated that it is not just about the cost of developing a technology. Rather, they lack resources which are at their disposal to train the employees to use the Metaverse. And, one of the main impediments is the cost needed to train the employees. Respondents narrated that such training also requires a substantial amount of effort and time besides the money factor involved.

> We assessed that the cost of training employees to use the Metaverse is huge. We are not sure how much time we have to put in to train the staff. I guess that would be costly and a time-taking effort. I have another concern that we have to keep our employees updated and continue to train them throughout to use the Metaverse as this technology keeps evolving (R14).

Some respondents also discussed the cost of maintaining and integrating the technology at the same time. They argued that the Metaverse requires regular maintenance and they further need to incorporate this technology with other systems. Effort is required to ensure that the Metaverse remains functional, secure, while data is safely stored to use the technology at its full potential.

> The cost of maintaining and integrating the Metaverse is far beyond our reach. The regular maintenance is so expensive, as we have to invest in purchasing new hardware and software to keep the technology going. Also, merging the Metaverse with our current business systems to reap the best benefits of the Metaverse is costly due to the complexity of the technology (R30).

4.6 Legal and ethical challenges

In supply chains, there is a growing need for robust ethical practices due to transparency and accountability issues. The induction of the Metaverse makes this task even more challenging due to an intersection between new heavy technology and ethical standards. Our discussion with respondents revealed some legal and ethical challenges pertaining to the adoption of the Metaverse in supply chains. Precisely, respondents pointed out the issue of privacy in the management of supply chain operations. In other words, they narrated that the Metaverse technology requires a substantial collection and storage of large amount of sensitive information about other member firms such as suppliers. They stated that even if they can access their supplier's data to implement the Metaverse, the onerous remains on them to ensure that such data is protected from unauthorized access and misuse. Therefore, before bringing the Metaverse into supply chains, firms need to put in robust security measures to safeguard the data of other member firms.

> Well, once we get on rolling with the Metaverse, it is our job to ensure that our suppliers' data transmitting through this technology remain protected and can't get in unauthorized hands. Unfortunately, we do not have such protocols in place to protect their privacy (R22).

More respondents particularly referred to intellectual property rights as one of the utmost important variables in the Metaverse. They argued that they, as well as other supply chain member firms, do not have proper protections and legal rights to store and retain their member firm's information. The ownership and control of digital assets, supply chain models and AI-generated logistics data in the Metaverse remain unclear. Therefore, it is important for firms as well as external stakeholders, such as government bodies to work together and create a system that respects the rights of their partnering firms.

> The Metaverse is definitely a good idea. But it has legal implications. Firms need to understand the laws governing the implementation of the Metaverse in our work. What does a country's law say about the right to privacy and ownership of digital assets? How will business and governments prepare themselves to enforce such laws across the Metaverse? These questions are yet to be answered (R15).

4.7 Lack of technology infrastructure and capabilities

The Metaverse relies on a robust technological infrastructure, such as high-speed Internet. Unfortunately, implementing the Metaverse technology in supply chains is even more challenging due to suppliers and customers unwillingness to compromise, lack of practices before implementation and customer concerns and issues, to name a few. Discussions with respondents unveiled that implementing the Metaverse in SCM requires advanced technological infrastructure and capabilities. It further requires an in-depth understanding of various technologies that are linked with the Metaverse such as blockchain. Respondents further stated that the Metaverse requires the integration of several "Internet of Things" devices, let alone, the importance of cloud computing and artificial intelligence technology. They further stated that one of the main technical challenges is seamless connectivity and communication between the firms that make up the Metaverse. Consider the quote below.

> We face huge challenges to ensure the seamless connection and communication between firms that make up the Metaverse. There is still a lot to be done to build a secure and robust network to easily transfer data between IoT devices and the cloud. Much work still needs to be done to ensure that correct protocols are in place to process and analyze this data as well (R8).

Besides, IoT, some respondents referred to the other technical challenges that impede the implementation of Metaverse in the supply chain. For instance, some respondents pinpointed that they do not have access to high-speed and reliable Internet to implement this technology. While other respondents precisely referred to the "Human-Machine Interaction", which works as a bridge for users to interact with machines. They mentioned that HMI is not up to the par yet and that users are not fully able to interact with machines in a way that is natural and efficient. Consider the quote below.

> Well, definitely, Metaverse requires fast and reliable internet/intranet connection to exchange data between partnering firms. We need access to fifth generation wireless network or fiber-based connections. Unfortunately, some of our partnering firms do not have such high-level connectivity yet, which hampers the use of Metaverse (R27).

As managers across firms interact with Metaverse through digital devices, including VR and computers, it is evident that HMI is efficient, seamless and very much intuitive and that managers are able to interact with machines in a way that is natural. We do not have such a robust HMI yet. Such robustness will improve the overall efficiency of data transfer across firms. Some respondents also reported that the need for advanced technological infrastructure is a big obstacle to deploying Metaverse in supply chains. They referred that lack of cutting-edge technology can harm communication, which is essential for a daily day-to-day running of Metaverse in the supply chain. They also argued that firms do not have access to high-performing computing and devices. Moreover, the Metaverse still lacks the high-end graphics that process units and other technology for use in the Metaverse.

Table 4 depicts the synthesis of multiple case study analyses and a summary of findings.

5. Discussion

5.1 Contribution to theory

By applying the TOE framework (Tornatzky and Fleischer, 1990), this study provides a structured and comprehensive analysis of the barriers to Metaverse adoption in SCM. The framework highlights the interplay between technological, organizational and environmental factors, offering a robust theoretical foundation for understanding the challenges associated with Metaverse adoption. This approach not only enhances the academic rigor of the study but also provides actionable insights for practitioners seeking to overcome these barriers. The findings reveal that addressing these challenges can unlock significant benefits for supply chain operations, revolutionizing and evolving them beyond what Industry 4.0 technologies can achieve independently. For instance, the integration of the Metaverse can enhance Industry 4.0 technologies through better connectivity, advanced simulation systems and artificial intelligence, transforming supply chain operations across the board. Further, this study articulates the detailed theoretical contributions, framed within the context of the TOE framework.

The study identifies a lack of collaboration between firms as a critical barrier to Metaverse adoption in SCM. Drawing on the technological-organizational and environmental

Table 4. Cross-case analysis of barriers to the adoption of metaverse in supply chain

No. Of cases	Lack of collaboration between supply chain firms	Lack of commitment from top management	Timid organizational culture	Lack of awareness and education	Financial challenges	Legal and ethical challenges	Lack of technological infrastructure and capabilities
Case Study I	Distributors and retailers fail to maximize the use of Metaverse technology Metaverse only used by manufacturers	Government and funding bodies do not intend to learn the importance/ benefits of Metaverse in SCM	Centralized decision-making is prone to implementing Metaverse in firms Many hierarchical layers in a firm impede the idea of implementing Metaverse	The utility of Metaverse is not beneficial to the supply chain The process of implementing Metaverse is very complex in SCM	The cost of developing Metaverse technology is too high The cost of maintaining Metaverse technology is too high The cost of integrating Metaverse technology is too high	Issue of privacy while implementing Metaverse technology in SCM Intellectual property rights may be at stake and subject to misuse in SCM No legal rights to store and retain the partnering firm’s data in SCM	Lack of high speed and reliable Internet to implement Metaverse in SCM Human Machine Interaction is not up the par yet Seamless connectivity and communication between firms to implement Metaverse is weak
Case Study II	Metaverse is mainly used in the manufacturing sector	Government and funding bodies do not intend to learn the importance/ benefits of Metaverse in SCM Funding bodies reluctant to generate funds for supply chain firms to implement Metaverse	Managers’ risk-averse attitude to is a hurdle to implementing Metaverse	SC firms are not fully aware of the potential benefits of the Metaverse	The cost of developing Metaverse technology is too high The cost of maintaining Metaverse technology is too high The cost of integrating Metaverse technology is too high	Issue of privacy while implementing Metaverse technology in SCM Intellectual property rights may be at stake and subject to misuse in SCM No legal rights to store and retain the partnering firm’s data in SCM	Lack of high speed and reliable Internet to implement Metaverse in SCM Human Machine Interaction is not up the par yet

(*continued*)

Table 4. Continued

No. Of cases	Lack of collaboration between supply chain firms	Lack of commitment from top management	Timid organizational culture	Lack of awareness and education	Financial challenges	Legal and ethical challenges	Lack of technological infrastructure and capabilities
Case Study III	Distribution channel's weakest links to implement Metaverse in SCM	Funding bodies reluctant to generate funds for supply chain firms to implement Metaverse	Centralized decision-making is prone to implementing Metaverse in firms Many hierarchical layers in a firm impede the idea of implementing Metaverse	Issue of diffusion is a hurdle to accepting the utility of Metaverse in SCM The process of implementing Metaverse is very complex in SCM	The cost of developing Metaverse technology is too high The cost of maintaining Metaverse technology is too high	Issue of privacy while implementing Metaverse technology in SCM Intellectual property rights may be at stake and subject to misuse in SCM No legal rights to store and retain the partnering firm's data in SCM	Integration of "IoT" between firms in SCM is not robust enough to implement Metaverse technology
Case Study IV	Retailers do not discuss Metaverse technology with partnering firms Distribution channels weakest links to implement Metaverse in SCM	Government does not show commitment to implement Metaverse	Managers' risk-averse attitude to is a hurdle to implementing Metaverse Managers do not consult or reluctant to take chances	SC firms are not fully aware of the potential benefits of Metaverse The process of implementing Metaverse is very complex in SCM	The cost of developing Metaverse technology is too high The cost of maintaining Metaverse technology is too high The cost of integrating Metaverse technology is too high	Issue of privacy while implementing Metaverse technology in SCM Intellectual property rights may be at stake and subject to misuse in SCM No legal rights to store and retain partnering firm's data	Lack of high speed and reliable Internet to implement Metaverse in SCM Human Machine Interaction is not upto the par yet

(*continued*)

Table 4. Continued

No. Of cases	Lack of collaboration between supply chain firms	Lack of commitment from top management	Timid organizational culture	Lack of awareness and education	Financial challenges	Legal and ethical challenges	Lack of technological infrastructure and capabilities
Case Study V	Metaverse is mainly used in manufacturing sector Distributors and retailers fail to maximize use of Metaverse	Government and funding bodies do not intend to learn the importance/benefits of Metaverse in SCM Funding bodies reluctant to generate funds to supply chain firms to implement Metaverse	Centralized decision-making is prone to implementing Metaverse in firms Many hierarchical layers in a firm impedes the idea of implementing Metaverse	Issue of diffusion is a hurdle to accept the utility of Metaverse in SCM The process of implementing Metaverse is very complex in SCM	The cost of developing Metaverse technology is too high The cost of maintaining Metaverse technology is too high The cost of integrating Metaverse technology is too high	Issue of privacy while implementing Metaverse technology in SCM Intellectual property rights may be at stake and subject to misuse in SCM No legal rights to store and retain the partnering firm's data in SCM	Seamless connectivity and communication between firms to implement Metaverse is weak Lack of high speed and reliable Internet to implement Metaverse in SCM

Source(s): Authors' own work

framework, this finding highlights the importance of communication channels and social systems in the adoption process. While current literature acknowledges that firms' inability to integrate the Metaverse is exacerbated by a lack of collaboration, Munaro and Tavares (2023), Dwivedi *et al*. (2022) also found that lack of collaboration is a key factor that hinder intention to work with Metaverse on a large scale and small-scale project. Therefore, this paper extends this understanding by demonstrating how a lack of collaboration between suppliers and buyers can hinder the design process of the Metaverse technology. Furthermore, insufficient collaboration among retailers, wholesalers and distributors can negatively impact the end-consumer experience. These findings align with the TOE framework, which emphasizes the role of inter-organizational networks in technology adoption (Rogers and Leuschner, 2004).

The study underscores the critical role of stakeholder support in the successful implementation of the Metaverse technology in SCM. Using the TOE framework, this paper explains stakeholders' reluctance to adopt the Metaverse as a function of perceived usefulness and perceived ease of use. While existing literature highlights the importance of stakeholder commitment (Suzuki *et al*., 2020; Queiroz *et al*., 2023), it does not explain why stakeholders are hesitant. This study contributes by revealing that stakeholders are reluctant to adopt the Metaverse due to their aversion to learning new technologies and their underestimation of the benefits it can bring to supply chain operations. These insights align with the TOE framework, which posits that user acceptance is driven by the perceived benefits and ease of use of technology (Davis, 1993). Moreover, recent literature also provides support to the notion. For instance, Besson and Gauttier (2024) found that stakeholders are usually risk-averse when it comes to learning new technology as well as the benefits attributed to this.

The study highlights the role of organizational culture in the successful execution of Metaverse technology. Building on the TOE framework, this paper identifies centralized decision-making, risk-averse top management and a preference for consistency as cultural traits that hinder Metaverse adoption. While existing literature links traditional organizational culture to the failure of Metaverse implementation (Arena *et al*., 2023; Assoratgoon and Kantabutra, 2023), this study empirically demonstrates how these cultural traits create resistance to change. These findings also contribute to the understanding of how organizational culture influences the adoption of technology within firms, supported by current literature on the cultural alignment with Metaverse. For example, Trivedi and Negi (2023) found that firms rooted within traditional organizational cultures are usually reluctant to adopt change, particularly in reference to technology adoption, as employees perceive such changes may jeopardize their jobs.

The study reveals that the adoption of the Metaverse is restricted due to its incompatibility with existing technologies and the challenges of integrating it with other virtual programs. Framed within the TOE framework, this finding highlights the technological context as a critical factor in Metaverse adoption. The need for high technical competence to achieve seamless integration poses a significant barrier, as noted in prior literature (Mozumder *et al*., 2022; Queiroz *et al*., 2023). This study extends this understanding by emphasizing the role of perceived compatibility in shaping adoption decisions.

The study identifies financial challenges as a major barrier to Metaverse adoption in SCM. Using the TOE framework, this paper categorizes these challenges into three types: (1) the cost of developing the technology, (2) the cost of training employees and (3) the cost of maintaining the technology. While recent literature hints at financial challenges (Bhattacharya and Chatterjee, 2022; Queiroz *et al*., 2023), this study provides a detailed empirical analysis of these costs, contributing to the economic dimension of the TOE framework. These findings are novel in the context of Metaverse adoption in SCM.

The study uncovers legal and ethical challenges related to data privacy, intellectual property rights and unauthorized use of sensitive information. These findings align with the environmental context of the TOE framework (Bag *et al*., 2023), which considers external factors such as regulatory and ethical concerns. To the best of our knowledge, this is the first study to outline these challenges in the context of Metaverse adoption in SCM, contributing to the growing body of literature on the ethical implications of emerging technologies.

The study identifies a lack of cutting-edge technology as a barrier to Metaverse adoption. Drawing on the TOE framework, this paper highlights the absence of high-speed Internet connectivity and seamless human-machine interaction as critical technological limitations. While prior studies have noted the lack of advanced technology as a barrier (Dwivedi *et al.*, 2022; Tsang *et al.*, 2022), this study provides specific insights into the technological tools that are missing, contributing to the technological context of the TOE framework.

5.2 Implications for firms

This study provides actionable insights for firms aiming to adopt Metaverse technology in SCM. The research identifies key barriers and proposes practical solutions to address them as follows: Collaboration between firms is critical for Metaverse implementation. To achieve this, supply chain firms should establish structured partnership agreements with clear objectives for Metaverse adoption. One approach is to form consortiums where multiple supply chain partners jointly invest in Metaverse-based infrastructure, ensuring shared risks and benefits. Additionally, firms can implement blockchain-based smart contracts to automate and enhance trust between supply chain stakeholders, minimizing disputes and errors during implementation. Firms must undergo structural transformation to align with the Metaverse requirements. Specifically, decentralization in decision-making can be facilitated through digital governance frameworks, where authority is distributed via smart contracts or AI-driven decision-support systems. Firms should proactively address legal and ethical concerns by adopting internationally recognized cybersecurity standards (e.g. ISO/IEC 27001 for information security management). Implementing blockchain-enabled distributed ledger technology (DLT) ensures data integrity, preventing unauthorized access to proprietary information. As a practical measure, firms can pilot a permissioned blockchain model where only verified supply chain members access relevant data. Legal teams should also collaborate with policymakers to develop industry-specific regulations for Metaverse-based SCM applications. Given the financial constraints of Metaverse adoption, firms should leverage cost-sharing models where supply chain partners co-finance technology adoption.

Another practical strategy is the adoption of cloud-based Metaverse solutions instead of building in-house infrastructure, reducing capital expenditure. Perhaps, firms can engage with technology providers through outcome-based pricing models, where costs are linked to performance metrics rather than fixed investments. On the other hand, firms must implement advanced authentication mechanisms to safeguard sensitive supply chain data. Multi-factor authentication and biometric verification within the Metaverse environment can prevent unauthorized data access. To further enhance security, firms can establish zero-trust architecture, ensuring continuous verification of users and devices before granting access to supply chain systems. Suppliers concerned about data visibility can adopt role-based access control to define hierarchical data permissions, ensuring only relevant stakeholders have access to specific datasets. To overcome connectivity and interoperability issues, firms should invest in high-speed, scalable cloud computing solutions. Partnering with cloud service providers (e.g. AWS, Microsoft Azure) ensures seamless integration with Metaverse applications. Moreover, firms should implement edge computing to process data closer to the source, reducing latency in Metaverse-based SCM operations. Firms should also ensure that APIs (Application Programming Interfaces) are developed for seamless communication between legacy SCM software and Metaverse platforms. Table 5 outlines key strategies that firms can potentially deploy to overcome the barriers to the adoption of the Metaverse in digital supply chains.

5.3 Implications for managers

The Metaverse offers transformative opportunities for supply chain managers, but its effective utilization requires structured implementation strategies. To foster seamless collaboration, managers should utilize Metaverse-enabled virtual meeting spaces integrated with real-time

Table 5. Identification of barriers and key strategies to overcome these barriers

Research objective I: Identification of key barriers	Research objective II: Key action plan/strategies to overcome key barriers
Lack of collaboration between member firms	Discusses benefits associated with implementing Metaverse, including improved visibility of products at all stages of the supply chain, new avenues to measure and improve sustainability and greater connectivity
Lack of commitment from top management	Mention the benefits of implementing Metaverse in the form of supply chain optimization through real-time information on product lead times, delays and deliveries and supply chain and logistics costs, accounting for over 70%
Timid/rigid organizational culture	Discuss how implementing Metaverse will streamline organizational culture through improved meetings, work from anywhere, enhanced training and development programs and a more diversified workplace
Lack of awareness and education	Host virtual events across member firms provide training to employees on how to use and maintain Metaverse
Financial challenges	Ascertain the size and complexity of Metaverse depending on the size of the firm Look for a development team charging reasonable costs. Outsourcing services from developing countries like China will reduce the development costs of Metaverse
Legal and ethical challenges	Introduce robust regulatory frameworks and address legal uncertainties surrounding regulations and privacy Develop robust security protocols Ensure data integrity through DLT
Lack of technological infrastructure	Leverage blockchain technology, peer network and artificial intelligence as they are key components in Metaverse

Source(s): Authors' own work

analytics. For example, companies can use Metaverse digital twins to conduct cross-functional meetings where managers visualize and test supply chain scenarios in real time before implementation. Managers should also invest in immersive collaboration platforms (e.g. Spatial.io, Microsoft Mesh) to simulate supply chain workflows. Managers should work with other teams to establish Metaverse-based training simulations that allow employees to engage in hands-on virtual simulations. For instance, a logistics company could use VR-based Metaverse training to simulate warehouse operations and train employees on optimizing inventory management. This reduces the risks of real-world errors and accelerates the learning curve for new technologies. Managers can also leverage AI-powered analytics tools within the Metaverse to enhance supply chain visibility. For example, AI and IoT-driven dashboards can analyze Metaverse-generated supply chain data to provide predictive insights on demand forecasting and inventory optimization. Additionally, managers should implement real-time tracking systems integrated with IoT-enabled Metaverse applications to visualize the flow of goods and identify bottlenecks before they impact operations.

Results suggest that the Metaverse allows managers to create 3D supply chain models for better process mapping. A practical example includes using digital twins to represent manufacturing plants and logistics hubs in a virtual environment, enabling scenario testing for different supply chain disruptions (e.g. supplier delays and route optimization). This enables proactive decision-making and reduces operational risks. Furthermore, to mitigate cybersecurity threats, managers should implement decentralized identity management systems to authenticate users securely. One strategy would be using Self-Sovereign Identity frameworks, which allow supply chain firms to maintain control over their digital identities while ensuring secure access management within Metaverse environments. Supply chain managers should explore AI-driven chatbots and virtual assistants to automate routine SCM tasks. For instance, AI-driven avatars or virtual assistants can assist in responding to supplier inquiries, tracking shipments and monitoring inventory levels, reducing administrative burdens on managers and enhancing efficiency. Managers should also engage in creating an interdepartmental Metaverse task force in their IT, logistics and procurement departments to coordinate a successful implementation and further ensure alignment on available infrastructure, compliance programs and training of workforce to address the lack of cross-functional readiness amongst employees.

6. Limitations and future research

This study comes with certain limitations. To begin with, the study uses a relatively small sample of 30 interviews to explore the challenges of executing the Metaverse technology in SCM, therefore its results cannot be generalized to a border population. Also, the main goal of this study is to build a theory in the area of SCM using the Metaverse technology, its results should not be generalized to a broader population. Moving on, the study uses cause-and-effect relations and collects results only at one point in time. This is another limitation.

The study provides several avenues for future research. First, the results of this study should be empirically tested through quantitative surveys to demonstrate its acceptability and validity. Particularly, future research should target specific industries such as aerospace manufacturing and automotive supply chains, where immersive technologies like the Metaverse may yield different results. Second, the study encourages future research to collect data at various points in time through longitudinal surveys. This would give a better picture of the results. To be specific, longitudinal case studies within selected industries, particularly automotive, could provide rich insights into adoption dynamics and organizational learning. Third, future research should collect data in dyads (buyer–supplier) to enhance the generalizability of the findings. Fourth, future research should unveil the potential drivers or antecedents of the Metaverse in the supply chain context. Fifth, many respondents highlighted financial challenges to implementing the Metaverse technology. Therefore, future research should find ways to mitigate the cost of implementing Metaverse in SCM. In other words, what are the financial implications for firms to consider before investing in the technology? Does the cost of implementing Metaverse in SCM outweigh the benefits associated with implementing it? Also, future research could Similarly, explore the possibility of overcoming technical challenges associated with implementing Metaverse in SCM. Therefore, future research should explore whether it is possible to address the many technical challenges to adopting the Metaverse technology in SCM. Perhaps, future research could engage with technical feasibility studies within logistics sectors like warehousing and distribution centers to identify potential scalable solutions. Sixth, respondents argued that firms can encourage innovation, which can ultimately lead to a successful implementation of the Metaverse. Future research should explore how supply chain member firms can work together to create a system that respects the rights of a creator as well as encourages innovation with or between firms. Seventh, many respondents listed the potential challenges of ensuring data protection in Metaverse technology. They argued that ensuring that data is protected from unauthorized access requires immediate attention before implementing the Metaverse. Therefore, future research should delve into how supply chain firms can put in place robust security measures to protect users' privacy. Precisely, a comparative study between highly regulated industries like pharmaceutical supply chains versus less regulated sectors like consumer goods could reveal varying risks and some unique data governance requirements for Metaverse-enabled supply chains.

7. Conclusion

The Metaverse represents a transformative opportunity for SCM, offering the potential to integrate physical and digital dimensions in innovative ways. This study contributes to both theoretical and practical understandings by identifying key barriers and highlighting implications for adoption. The conclusions are as follows:

(1) Seven key barriers to Metaverse adoption in SCM were identified and contextualized, aligning with and extending existing literature on digital transformation and technology adoption.

(2) The Metaverse has the potential to revolutionize SCM by enabling immersive, digital-first operations that enhance innovation, efficiency and collaboration.

(3) The TOE framework can provide a robust lens through which to understand these barriers, revealing the interplay between internal capabilities and external contingencies.

(4) Technological barriers—including lack of interoperability, cybersecurity risks and high implementation costs—remain the most immediate challenges to adoption in digital supply chains.

(5) Organizational barriers, such as cultural resistance, lack of skilled personnel and insufficient leadership support, significantly impede implementation efforts.

(6) Environmental barriers, including regulatory ambiguity, ethical concerns and data privacy risks, reflect the external complexities that firms must navigate to successfully implement the Metaverse.

(7) The interconnected nature of these barriers underscores the need for a holistic strategy, as failure to address one domain may reinforce constraints in another.

(8) Strategic opportunities offered by the Metaverse in SCM include:

- Faster and more cost-effective product design and development.
- Improved procurement through virtual inspections and remote supplier audits.
- Enhanced supply chain transparency, traceability and real-time monitoring.
- Promotion of sustainability by reducing the need for physical travel and enabling virtual collaboration.

(9) Finally, firms must invest in strategic planning, workforce development and technological infrastructure to overcome these barriers and realize the potential benefits of Metaverse integration.

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Appendix

Interview protocol

(Authors' own work).

Main questions:

(1) What is Metaverse?

(2) How is the Metaverse transforming supply chains?

(3) How is the Metaverse implemented in your business operations?

(4) How the Metaverse is different from Industry 4.0?

(5) What are some of the challenges/barriers to implementing Metaverse?

(6) What initiatives you have taken to address any of these challenges

(7) How do you believe such barriers are unique given the supply chain context?

Probing questions:

(1) Please tell us more about the phase you are in while implementing Metaverse?

(2) Are you complementing industry 4.0 technologies with the Metaverse? If yes, how?

(3) Could you tell us more about the objective of implementing the Metaverse?

(4) Could you please tell us more about the specific areas/operations in which you are implementing the Metaverse?
(5) We would like to know more about the technological challenges.
(6) Could you tell me more about the financial challenges?
(7) What do you mean by legal challenges to implementing the Metaverse in SCM?
(8) Could you tell us more about how ethical challenges impact the Metaverse in SCM?

Corresponding author
Atif Saleem Butt can be contacted at: atifbutt10@hotmail.com