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Exploring the impact of metaverse adoption on supply chain effectiveness: A pathway to competitive advantage

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In the rapidly evolving landscape of supply chain management, the advent of the metaverse presents a novel frontier with significant potential for enhancing operational effectiveness and excellence. This study aims to examine the effect of metaverse adoption on various dimensions of the supply chain, including resilience, agility, flexibility, and performance. Utilizing a quantitative research approach, the research analyzes survey data from a significant sample size of 737 organizations that have adopted metaverse technology into their supply chain operations. The employment of partial least squares structural equation modeling (PLS-SEM) offers a comprehensive understanding of the metaverse's role in enhancing the dynamism and efficiency of supply chains. This study contributes to the emerging field of digital transformation in supply chain management by providing empirical evidence on the effectiveness of metaverse technology. It bridges the gap in literature regarding the practical application of advanced digital solutions in enhancing supply chain operations and sets a foundation for future research in this area.

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1. Introduction

The emergence of metaverse technology has issued a paradigm shift in the way businesses operate and function. Metaverse technology is a virtual world that enables users to interact with each other in a three-dimensional space (Huang et al., 2023; Gupta, 2023; Momtaz, 2022; Bai & Bisht ,2022). As metaverse technology adoption gradually grows, it is crucial to understand its effect on various aspects of business operations. Researchers have studied the impact of metaverse on the business world to shed light on the opportunities and challenges facing small- or large-scale entrepreneurs and enterprises in the future (Yemenici, 2022). Previous studies have explored the impact of metaverse adoption in various fields such as education (Salloum, 2023; Felice, 2023; Song & Wang, 2023; Chinie et al., 2022), marketing (Cheah, 2023), and consumer behavior (Gupta, 2023). Despite this, there is a gap in the literature regarding the effect of metaverse adoption on supply chain effectiveness. Moreover, previous studies have researched the sustainability of metaverse technology (De Giovanni, 2023) and the influence of metaverse risks on supply chain sustainability (Maden, 2022). The aim of this study is to highlight the influence of metaverse adoption on supply chain effectiveness. The results will identify the potential benefits and challenges of metaverse adoption in supply chain management.

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Queiroz et al. (2023) argues that metaverse development in most supply chains and organizations is still in its early stages. However, it seems to have already attracted the attention of supply chains as a brand-new technology (Maden, 2022). Metaverse apps have been identified as having the potential to improve supply chain efficiencies. According to Yan (2023), the supply chain will one day be exposed to the metaverse environment due to the metaverse's escalating development. Koohang et al. (2023) suggest that the adoption of metaverse will impact various significant areas, including manufacturing, operations management, and retailing. However, immersive technologies in the metaverse present issues and challenges, such as privacy concerns and cybersecurity (Gupta, 2023; Sebastian & Babu, 2022). Despite the piqued interest in metaverse adoption, it's still at a nascent stage (Queiroz et al., 2023). A gap in the literature exists regarding the specific influence of metaverse adoption on key dimensions of supply chain effectiveness, such as agility, flexibility, and resilience. Existing studies, such as Queiroz et al., (2023), Emphasize the importance of high-quality research metaverse adoption on supply chain management among other related topics. Additionally, research is required to explore the integration of metaverse adoption with other Industry 4.0 technologies, such as AI, IoT, and Robotics to improve the performance of supply chain (AlHamad et al., 2022; Alshurideh et al., 2023a; Trivedi & Negi, 2023). Addressing these research gaps will offer valuable and significant insights for companies looking to leverage the metaverse in their supply chain procedures, supporting them to enhance performance and navigate dynamic business environments more effectively.

2. Literature Review

2.1 Supply Chain Resilience

Supply chain resilience is defined as the capability of a supply chain to recover from external disruptions and return to its ideal or original state (Xiao et al. 2012). This includes both the ability to adapt to the environment and to recover from the disruption. A supply chain system that is backed by Metaverse can address the challenges arising from the fragmentation of traditional blockchain platforms with varying standards and ineffective governance (Yan, 2023). Cui et al. (2022) suggests that supply chain resilience can be improved by adopting metaverse and related technologies. Barhmi (2023) has empirically explored the mechanisms through which supply chain capabilities devoted to resilience and risk management can enhance agility performance during times of disruption caused by unavoidable risks. Similarly, several researchers suggest that metaverse technology alongside other related technologies such as blockchain can improve supply chain resilience through enhancing visibility, flexibility, velocity, and facilitating more effective proactive risk management (Queiroz et al., 2023; Spieske & Birkel, 2021). Hence, this study proposes the following research hypothesis:

H_1: *Metaverse adoption positively influences Supply Chain Resilience.*

2.2 Supply Chain Performance:

Supply chain performance refers to the supply chain's ability to deliver the right product effectively and efficiently at the right time and location while minimizing logistics costs (Zhang & Okoroafo 2015). Sabry et al. (2021) found a significant relationship between management practices and supply chain performance. This is supported by Daneshvar et al. (2020), who emphasizes the significance of management for an efficient supply chain strategy to increase supply chain performance. Additionally, Aćimović et al. (2022) suggests that performance of logistics is a critical determinant of supply chain performance, which ultimately leads to be a key for organizational performance. Fadlianto et al. (2022) highlights the significance for effective supply chain performance in reducing costs, delivery delays, waiting times, and improving quality of products. Cristina (2021) noted that Artificial intelligence such as metaverse can increase supply chain performance. Similarly, Cherian et al. (2023) have also found that information technology capability is critical for supply chain performance post-COVID-19. It was determined by Queiroz et al. (2023) that adopting metaverse for operational activities will enhance the overall supply chain performance. Similarly, Trivedi & Negi (2023) indicates that metaverse and its utilization across various components of the supply chain will ultimately lead to a growth in the supply chain performance and overall profitability. Hence, this study proposes the following research hypothesis:

H_2: *Metaverse adoption positively influences Supply Chain Performance.*

2.3 Supply Chain Agility

Supply chain agility is the capability of a supply chain to offer customer-centric services and products, adapt to unforeseen challenges in distribution and logistics systems, and utilizing opportunities arising from these changes while sustaining the unexpected threats amidst a volatile and dynamic business environment (Christopher et al., 2004; Yusuf et al., 2014; Zhang & Sharifi, 2000). Supply chain agility capabilities are an important element in increasing the performance of the supply chain (Cherian et al., 2023). Similarly, Firmansyah and Siagia (2022) reported that supply chain agility mediates the link between information sharing and operational performance. In addition, integrating agility into supply chain processes can lead to competitive advantages (Mirabi et al, 2018). Şahin et al. (2017) claimed that supply chain agility is positively related to firm performance. The degree of flexibility in the supply chain procurement/sourcing, manufacturing, and processes directly influences a firm's supply chain agility (Swafford et al. 2006). According to Dwivedi et al., (2022), Metaverse adoption enables organizations to collect real-time customer feedback, improving agility and minimizing costs.

Likewise, the adoption of metaverse can improve flexibility (Chen, 2022), thereby improving supply chain agility. Furthermore, Al-Zabidi et al. (2021) reported that the Metaverse may expand agility as it provides opportunities for operations and supply chain (Queiroz et al., 2023). Hence, this study proposes the following research hypothesis:

H$_3$: *Metaverse adoption positively influences Supply Chain Agility.*

2.4 Supply Chain Flexibility

Supply chain flexibility is a key aspect that ensures a firm's ability to quickly respond to changes in demand and supply (Tukamuhabwa et al., 2015). Both the supply chain and firm performance are positively influenced by flexibility (Mukhsin et al., 2022). According to Luo et al. (2020), a flexible supply chain is essential to companies' ability to adapt to customers' needs and market conditions change, especially when uncertainty exists.

This is supported by (Yi et al., 2011), who reported that achieving better supply chain responsiveness could be done by improving supply chain flexibility and reducing uncertainties. Metaverse adoption can increase the flexibility of supply chain by enabling firms to leverage new platforms and technologies to enhance their supply chain and operation management (Alshurideh et al., 2023b). Queiroz et al. (2023) notes that the metaverse offers significant opportunities for supply chain and operations management, including improved communication, collaboration, and coordination between supply chain partners. Likewise, Potnis et al. (2023) discovered that blockchain technology (a key component of the metaverse), influenced supply chain flexibility and capabilities of firms. The study suggests that blockchain technology can enhance the traceability, visibility, and security of supply chains. This will allow companies to adapt to demand fluctuations and supply fluctuations. Hence, this study proposes the following research hypothesis:

H$_4$: *Metaverse adoption positively influences Supply Chain Flexibility*.

3. The study conceptual model

The study conceptual model is shown in Fig.1.

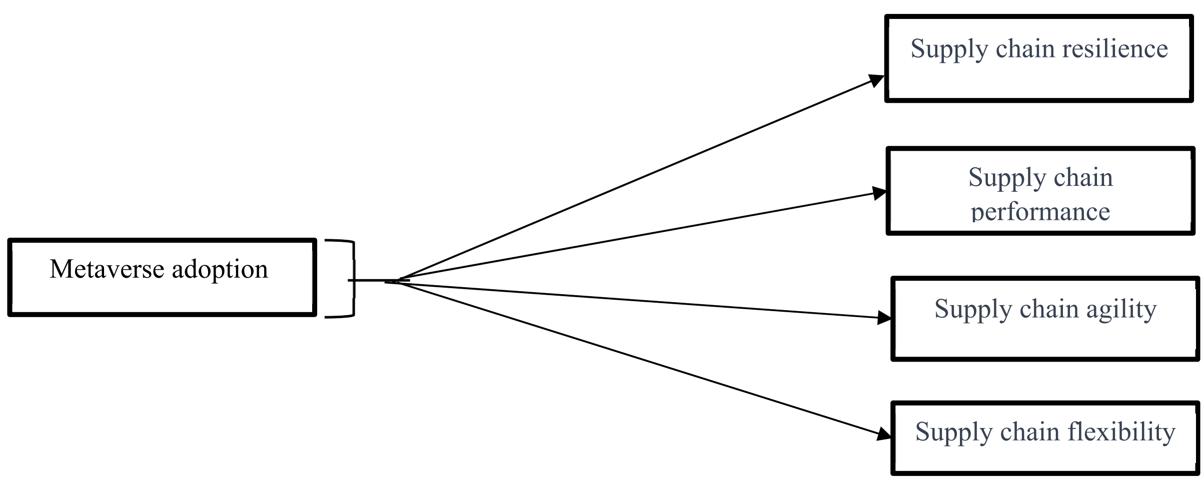

Fig. 1. Conceptual model.

4. Methodology

The sample was collected through an online closed-ended questionnaire, with data collection taking place from 16th July to 25th March 2022 from firms that adopted the metaverse in their supply chain operations. Before the distribution of survey questions and questionnaires, a pretesting process was conducted to confirm that the questions were reliable and valid. Five academics and practitioners have pretested the survey instrument to ensure its content validity. Based on prior studies, all items were measured on a 5-point Likert scale (1=strongly disagree; 5= strongly agree). The questionnaire is divided into three sections. In the first section, participants are asked about their age, gender, and income level. The second section contains 4 questions measuring metaverse items. The third section presents 16 questions related to supply chain resilience, performance, agility, and flexibility. The questionnaires were distributed to 900 participants, but only 737 were usable (81.8% response rate), the rest were excluded from the studies because of missing information. The demographics results found most respondents were female (70.4%), between 20 to 30 years old (53.9%), single (70.7%), with a bachelor’s degree (57.5%), 0 to 3 years of experience (60.7%), and were mid-level employees (60.1%).

Table 1
Respondents profile

Characteristic	Frequency	Percent	Characteristic	Frequency	Percent
Gender			**Educational level**		
Male	218	29.6	Secondary school	169	22.9
Female	519	70.4	Diploma	92	12.5
Age			Bachelor	424	57.5
Under 20	169	22.9	Masters	47	6.4
20 - less than 30	397	53.9	PhD	5	0.7
30 - less than 40	113	15.3	**Years of experience**		
40 -less than 50	46	6.2	0-3 years	447	60.7
50 -less than 60	10	1.4	3-5 years	124	16.8
Over 60	2	0.3	5-10 years	57	7.7
Marital status			more than 10 years	109	14.8
Single	521	70.7	**Levels of employee**		
Married	192	26.1	Senior-level	215	29.2
Divorced	19	2.6	Mid-level	443	60.1
Widowed	5	0.7	Executive-level	79	10.7

5. Results

Partial Least Squares-Structural Equations Modeling (PLS-SEM) was applied to the data analysis using SmartPLS 4.0. The data were analyzed using a two-step approach (Hair et al., 2017). The first step is to assess the measurement model, while the second step is to test the structural model. For the following reasons, we selected a PLS-SEM model. Firstly, it is recommended to use PLS-SEM if the research is focused on current theories (Urbach & Ahlemann, 2010). Secondly, it can be utilized effectively for exploratory analysis when complex models are used (Hair et al., 2021). Third, PLS-SEM analyzes the entire model rather than making subdivisions (Goodhue et al., 2017). Lastly, PLS-SEM allows the structural and measurement models to be analyzed simultaneously, resulting in accurate measurements (Barclay et al., 1995).

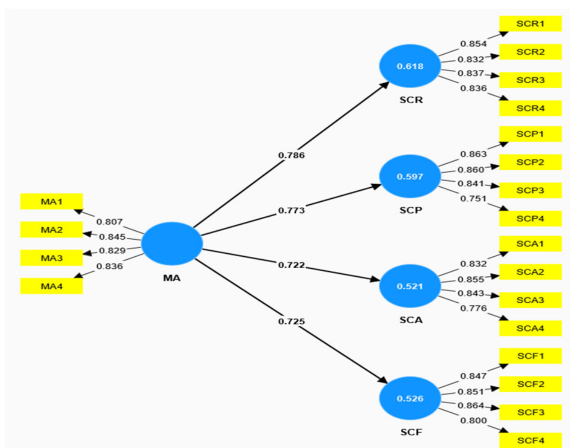

Fig. 2. Measurement Model

5.1 Measurement model assessment

Following the recommendation of Hair et al. (2017), the measurement model was assessed in terms of reliability, using Cronbach's alpha (CA), and composite reliability (CR), as well as validity, including convergent and discriminant. Table 2 and Fig. present the findings. 2. Cronbach's alpha (CA) and Composite Reliability (CR) are used to evaluate reliability. Cronbach's alpha (CA) values exceeded the acceptable threshold of 0.7 (Nunnally and Bernstein, 1994), ranging from 0.845 to 0.861. Similarly, Composite Reliability (CR) values exceed the accepted threshold of 0.6 (Hair et al., 2010). Convergent validity is assessed using loadings and average variance extraction (Hair et al. 2017). For all items, factor loadings ranged between 0.751 and 0.864, which exceeds the recommended threshold of 0.7. The AVE values exceed the acceptable limit of 0.5. These results indicate satisfactory validity and reliability of the measurement model.

Fornell and Larcker's (1981) criteria was used to assess the discriminant validity of the model. According to the criteria, the square root of the AVE for every construct should exceed the correlation coefficients between the constructs. The diagonal values in Table 3 represent the square roots of the AVEs for each construct, which are highlighted in bold. As the square root of each construct's Average Variance Extracted (AVE) exceeds its correlation with other constructs, the discriminant validity was met (Fornell and Larcker, 1981).

Table 2
The measurement model

Constructs	Items	Factor loading	Cronbach's alpha	CR	AVE
Metaverse adoption	MA1	0.807	0.849	0.898	0.688
	MA2	0.845			
	MA3	0.829			
	MA4	0.836			
Supply chain resilience	SCR1	0.854	0.861	0.905	0.705
	SCR2	0.832			
	SCR3	0.837			
	SCR4	0.836			
Supply chain performance	SCP1	0.863	0.848	0.898	0.689
	SCP2	0.860			
	SCP3	0.841			
	SCP4	0.751			
Supply chain agility	SCA1	0.832	0.845	0.896	0.684
	SCA2	0.855			
	SCA3	0.843			
	SCA4	0.776			
Supply chain flexibility	SCF1	0.847	0.861	0.906	0.707
	SCF2	0.851			
	SCF3	0.864			
	SCF4	0.800			

Notes: CR = Composite reliability; AVE = Average variance extracted.

5.2 Model fit

In the evaluation of the model fit within the (PLS-SEM) framework, we utilized a suite of indicators provided by SmartPLS. The Standardized Root Mean Square Residual (SRMR) serves as a critical measure, reflecting the disparity between the observed correlations and the model-implied correlation matrix (Hair et al. 2016). An SRMR value of 0.053 for the Saturated model indicates a commendable fit, considering that values below 0.08 generally signify an acceptable fit (Hu and Bentler, 1998). The Saturated model's SRMR value is markedly lower than that of the Estimated model, which stands at 0.114, hinting at a less favorable fit. The Normed Fit Index (NFI), with an ideal benchmark of 0.90, as suggested by (Bentler and Bonett, 1980), assesses the model fit by considering the Chi-square values in relation to a null or benchmark model (Lohmoller, 1989). Discrepancy functions, specifically the geodesic distance (d_G) and the Unweighted Least Squares (d_ULS), were computed to compare the empirical covariance matrix with the covariance matrix implied by the composite factor model, as per established guidelines (Hair et al., 2021; Dijkstra and Henseler, 2015).

Table 3
Discriminant validity: Fornell and Larcker criterion

Construct item	MA	SCA	SCP	SCF	SCR
MA	**0.829**				
SCA	0.722	**0.827**			
SCP	0.773	0.795	**0.830**		
SCF	0.725	0.759	0.794	**0.841**	
SCR	0.786	0.758	0.807	0.752	**0.840**

Notes: Diagonal values and bolded are square root of AVE, and off-diagonal values
are correlation coefficients. MA = Metaverse adoption; SCA = Supply chain agility; SCP = Supply chain performance; SCF = Supply chain flexibility; SCR = Supply chain resilience

The Saturated model reported d_G and d_ULS values of 0.325 and 0.588, respectively, while the estimated model exhibited higher values of 0.533 for d_G and 2.717 for d_ULS, further substantiating the relative fit superiority of the Saturated model. The Chi-square values reinforce this interpretation, with the Saturated model presenting a value of 1328.775 compared to the Estimated model's 1875.972. This indicates that the magnitude of the goodness-of-fit for the PLS-SEM model was suitable for establishing the overall validity of the global PLS model. The results are summarized in Table 4.

Table 4
Model fit indicators

	Complete mode	
	Saturated model	Estimated model
SRMR	0.053	0.114
d_ULS	0.588	2.717
d_G	0.325	0.533
Chi-square	1328.775	1875.972
NFI	0.870	0.816

5.3 *Structural model*

Table 5 and Fig. 3. presents the findings. To test the model, this study employed bootstrapping with 5000 samples. The structural model's assessment included a review of the coefficient determination (R^2), effect size (F^2), predictive relevance (Q^2), and the path coefficient (β) (Zheng et al., 2021). This study used (R^2), as a measure for predicting in-sample outcomes for all dependent constructs, as suggested by (Hair et al., 2020). R^2 values of 0.25, 0.50, and 0.75 are interpreted as weak, moderate, and strong, respectively (Hair et al., 2011). The R^2 for supply chain resilience (SCR) stands at 0.618, showing that metaverse adoption accounts for 61.8% of SCR's variance. For supply chain performance (SCP), the R^2 is 0.597, indicating metaverse adoption explains 59.7% of the variance in SCP. The R^2 for supply chain agility (SCA) is 0.521, showing that 52.1% of the variance in SCA is due to metaverse adoption. Lastly, the R^2 for supply chain flexibility (SCF) is 0.526, suggesting metaverse adoption accounts for 52.6% of SCF's variance. As for the effect size (F^2), Cohen (1988) classifies effects larger than 0.02 but smaller than 0.15 as small, those between 0.15 and 0.35 as medium, and those greater than 0.35 as large. In our study, all effects fell into the large category. The Q^2 values exceeded zero, indicating exceptional predictive relevance (Rehman Khan and Yu, 2021). Regarding path coefficients (β), hypothesis 1 proposes that Metaverse adoption positively influences Supply Chain Resilience. The results support hypothesis 1 (β = 0.786, p < 0.001). Hypothesis 2 proposes that Metaverse adoption positively influences Supply Chain Performance. The results support hypothesis 2 (β = 0.773, p < 0.001). Hypothesis 3 proposes that Metaverse adoption positively influences Supply Chain agility. The results *support* hypothesis 3 (β = 0.722, p < 0.001). Hypothesis 4 proposes that Metaverse adoption positively influences Supply Chain flexibility. The results support hypothesis 4 (β = 0.725, p < 0.001).

Table 5
The structural model

Hypotheses	Relationship	Path	t-value	p-value	Direction	Results
H1	MA → SCR	0.786	40.627	0.000	Positive	Supported
H2	MA → SCP	0.773	33.370	0.000	Positive	Supported
H3	MA → SCA	0.722	27.327	0.000	Positive	Supported
H4	MA → SCF	0.725	26.990	0.000	Positive	Supported
Coefficient determination						
$R^2_{SCR} = 0.618$ $R^2_{SCP} = 0.597$ $R^2_{SCA} = 0.521$ $R^2_{SCF} = 0.526$						
Effect size						
$F^2_{SCR} = 1.620$ $F^2_{SCP} = 1.481$ $F^2_{SCA} = 1.087$ $F^2_{SCF} = 1.110$						
Predictive relevance						
$Q^2_{SCR} = 0.617$ $Q^2_{SCP} = 0.595$ $Q^2_{SCA} = 0.518$ $Q^2_{SCF} = 0.524$						

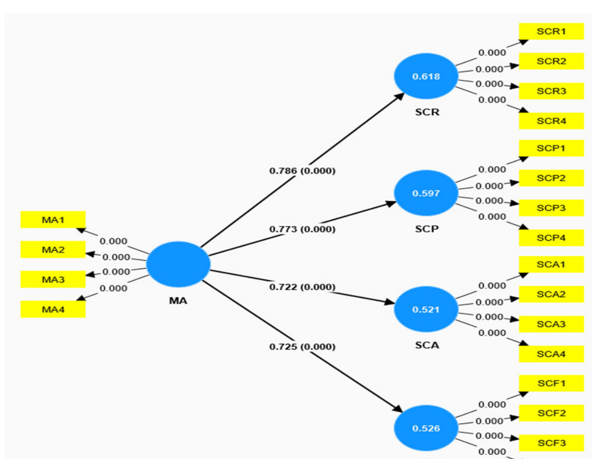

Fig. 3. Structural Model

6. Discussion

The study aims to investigate the influence of Metaverse Adoption (MA) on Supply Chain Resilience (SCR), Performance (SCP), Agility (SCA), and Flexibility (SCF). Results were as follows. Supporting Hypothesis 1, our results demonstrate a clear positive influence of metaverse adoption (MA) on supply chain resilience (SCR). This aligns with previous studies (Xiao et al., 2012; Cui et al., 2022; Barhmi, 2023), which have similarly highlighted the role of advanced technologies, such as the Metaverse, in boosting supply chain resilience. With these technologies, supply chains can adapt and recover faster from disruptions, which is crucial in today's rapidly changing business environment. In the context of supply chain performance, our findings support Hypothesis 2. The integration of the Metaverse within supply chain operations, as discussed in the works of Zhang & Okoroafo (2015) and Sabry et al. (2021), has shown a significant improvement in operational efficiencies and effectiveness. This reinforces the idea that technological advancements like the Metaverse are not mere adjuncts but are central to driving supply chain performance in contemporary settings. Further, the study substantiates Hypothesis 3, revealing a positive influence of metaverse adoption (MA) on supply chain agility (SCA). This is in line with the insights provided by Christopher et al. (2004) and Yusuf et al. (2014). The agility afforded by the Metaverse, as explained in these studies, enables supply chains to swiftly adapt to market changes and customer demands, a crucial capability in today's volatile market environment. Lastly, aligning with Hypothesis 4, our research found a positive impact of metaverse adoption (MA) on supply chain flexibility (SCF). Studies by Tukamuhabwa et al. (2015) and Luo et al. (2020) have underscored the necessity of flexibility in supply chain management, particularly in dealing with uncertainties and rapid market shifts. The Metaverse emerges as a pivotal technology in enhancing this flexibility, offering new avenues for supply chain adaptation and responsiveness. This study provides comprehensive evidence of the transformative impact of Metaverse adoption on enhancing supply chain agility, flexibility, agility, and resilience. These findings shed new light on how advanced digital technologies, such as metaverse, are reshaping supply chain strategies for the better.

7. Conclusion & Implications

This study investigates the impact of metaverse adoption on supply chain resilience, performance, agility, and flexibility. Analyzed the responses from 737 companies, our research has uncovered significant insights into how Metaverse adoption reshapes supply chain resilience, agility, performance, and flexibility. The findings indicate a substantial positive influence of Metaverse integration across these dimensions, suggesting that the Metaverse is not just an adjunct technology but a fundamental tool in enhancing supply chain dynamics.

The Metaverse's distinctive capabilities in immersive, interactive experiences have a pronounced impact on supply chain dynamics. This study highlights the Metaverse as more than an advanced technological tool; it emerges as a fundamental component in crafting agile, efficient, and competitive supply chains. The implications of these findings are substantial, offering both practitioners and theorists a new lens to view the role of digital innovation in supply chain management. The study further underscores the Metaverse's potential in facilitating real-time analytics, enhancing collaboration, and enabling dynamic decision-making processes across various supply chain stages.

This study serves as a foundation for future explorations into the digital transformation of supply chains. It provides a clear indication that businesses leveraging the Metaverse can anticipate not only enhanced operational efficiencies but also a strategic edge in the rapidly evolving global market. The study's insights are particularly valuable for companies seeking to understand and employ the Metaverse's capabilities to achieve a sustainable competitive advantage in their supply chain operations.

Recommendations and limitations

This research, while comprehensive in its exploration of the Metaverse's impact on supply chain management, encounters certain limitations that must be acknowledged. The most significant of these is the tendency of the respondent demographic towards companies already implementing or actively exploring Metaverse technologies. This bias may inadvertently skew the results towards a more favorable perception of the Metaverse's impact on supply chains. To address this limitation and enhance the robustness of future research, it is recommended that subsequent studies involve a more varied group of companies, particularly those that are either in the early stages of considering the metaverse or have not yet embarked on this technological journey. Such a diverse sample would yield a more universal and balanced understanding of the Metaverse's role in supply chain management, capturing a wide range of experiences and viewpoints.

Furthermore, future studies are suggested to track the evolving impact of the Metaverse on supply chains over time. As technology matures and its adoption becomes more widespread, understanding its long-term effects will be crucial. Additionally, there exists an opportunity for future research to investigate the specific strategies and practices employed by companies to integrate the metaverse into their supply chains. Investigating these strategies and their resulting operational, financial, and strategic outcomes would provide invaluable insights into the effective implementation and management of metaverse technologies in the supply chain domain. Such research could significantly contribute to the field by offering practical guidelines and frameworks for businesses aiming to navigate the complexities of digital transformation in supply chains.

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