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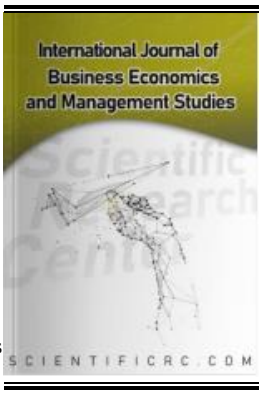

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Analysis of Digital Transformation Strategies in the Supply Chain of the Boiler and Pressure Vessel Industry with an Innovation and Technological Risk Management Approach

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Abstract

Digital transformation, as one of the most significant drivers of change across various industries, plays a fundamental role in enhancing innovation, managing technological risk, and improving supply chain performance. However, in the boiler and pressure vessel industry of Mazandaran, a comprehensive investigation into the relationship between digital transformation strategies and their managerial and operational outcomes has not yet been conducted. This study was carried out with the aim of analyzing digital transformation strategies in the supply chain of the boiler and pressure vessel industry, focusing on innovation management and technological risk management. The statistical population consisted of all experts and specialists employed in the Mazandaran boiler and pressure vessel industry—approximately 120 individuals. Due to the limited population size, a census method was used and all members were surveyed. The findings revealed that analyzing digital transformation strategies has a positive and significant impact on innovation management, technological risk management, and the supply chain. It was also determined that both innovation management and technological risk management play crucial roles in improving supply chain performance. Accordingly, it can be concluded that adopting digital transformation strategies, alongside effective innovation and technological risk management, can substantially enhance the flexibility, productivity, and competitiveness of the supply chain in this industry.

Keywords: Digital Transformation, Innovation Management, Technological Risk Management, Supply Chain, Boiler and Pressure Vessel Industry.

Introduction

Digital transformation in the supply chain of heavy and strategic industries—such as boilers and pressure vessels—represents an inevitable necessity in critical sectors like energy, oil and gas, and petrochemicals. Owing to the sensitive nature of its products and its direct role in industrial safety and infrastructure sustainability, this industry requires a supply chain that is flexible, transparent, and driven by technological innovation (Bienhaus & Haddud, 2018).

The introduction of smart technologies and digital transformation—particularly the use of artificial intelligence (AI), the Internet of Things (IoT), and big data analytics—has led to fundamental changes in processes such as design, raw material procurement, logistics, and risk management (Bottani et al., 2019). However, the key challenge in this field is not merely the adoption of advanced technologies, but rather the ability to manage technological risks and foster innovation within a sustainable and coherent strategic framework (Chen et al., 2023). Therefore, it is essential to design a scientifically grounded, evidence-based framework that enables the implementation of these technologies in the boiler and pressure vessel supply chain with minimal risk and maximum efficiency.

Experience from various industries demonstrates that integrating emerging technologies into supply chains requires a shift from traditional management and decision-making models. Research shows that the application of AI in logistics operations and demand forecasting can enhance efficiency and reduce error rates (Chien et al., 2020; Bae et al., 2019). Nevertheless, the success of such digital transformation depends on the proper management of technological risks—including data security, capital investment costs, and employee resistance to organizational change (Ellefsen et al., 2019). Furthermore, the integration of digital technologies must be aligned with innovation management to generate value across the entire supply chain (Cao, 2021).

In the boiler and pressure vessel industry—characterized by long production cycles and stringent quality requirements—managing innovation and technological risk not only transforms digital tools into a competitive advantage but also ensures business continuity and supports the development of export markets. From the perspective of markets and stakeholders, digital transformation in the supply chain of heavy industries is not merely a technological initiative; it is a socio-economic process that requires building trust, achieving technological acceptance, and aligning with key stakeholders (Alboqami, 2023; Anica-Popa et al., 2021).

For example, applying AI tools across the value chain can enhance transparency and reduce risks arising from delays or deficiencies in supply (Burakhanova et al., 2023). On the other hand, experiences from the retail industry in adopting AI indicate that advanced technologies improve performance only when behavioral and attitudinal barriers among consumers and employees are identified and effectively managed (De Bellis & Johar, 2020; Flavián et al., 2023). Therefore, the boiler and pressure vessel industry must redesign its digital transformation strategies not only from a technical perspective but also by addressing human and managerial risks. This calls for the development of a comprehensive, interdisciplinary approach that integrates innovation management with technological risk management.

Finally, research evidence shows that industries that have successfully implemented digital transformation have leveraged advanced approaches such as smart supply chains, data-driven decision-support systems, and interactive digital platforms (Aw et al., 2022; Calvo et al., 2023; Brau et al., 2024). These tools have not only increased responsiveness to market changes and supply chain disruptions but have also strengthened sustainable competitive advantage (Chung, 2021; Čirjevskis, 2022). However, the boiler and pressure vessel industry—given its complex and sensitive nature—remains at the early stages of systematically adopting such technologies. Therefore, the central question of this research is how digital transformation strategies in this industry's supply chain can be analyzed and redesigned through an innovation and technological risk management approach in order to mitigate technological risks while enhancing efficiency, safety, and international competitiveness.

Lecture review

Digital Transformation Strategies

Digital transformation, as one of the most significant phenomena of the present era, plays a vital role in redefining organizational structures and processes. Digital transformation strategies are essentially plans that organizations adopt to improve performance, increase productivity, and create new value by leveraging modern technologies. These strategies are typically designed with a focus on data-centricity, automation, artificial intelligence (AI), and the Internet of Things (IoT), aiming to adapt to the rapidly changing market environment.

Research shows that organizations that implement digital transformation strategies in an integrated and phased manner enjoy greater competitive advantages such as improved service quality and greater flexibility in responding to customer needs (Har et al., 2022; Mithas et al., 2022).

A key dimension of digital transformation strategies is the level of an organization's digital maturity. Digital maturity models—particularly in manufacturing industries and supply chains—help organizations assess their digital readiness and plan their transition to a fully digital enterprise. García-Reyes et al. (2022) emphasize that moving toward Supply Chain 4.0 requires digital transformation strategies that incorporate not only technological tools but also cultural and organizational changes. In this context, companies increasingly leverage AI and machine learning as key elements of their digital transformation strategies to improve decision-making and forecasting (Hasija & Esper, 2022).

Digital transformation strategies also encompass ethical and social aspects. The widespread use of AI in retail and service industries has raised new issues such as consumer trust, social acceptance, and ethical challenges. Giroux et al. (2022) show that integrating AI into organizational decision-making can reduce consumers' feelings of guilt and lead to different ethical outcomes compared to human decision-making. This underscores the need to rethink digital transformation strategies, which cannot be confined to the technical dimension alone but must also consider human, cultural, and ethical factors.

From a strategic management perspective, digital transformation strategies must be aligned with the organization's long-term vision and business model. Woods et al. (2022) argue that technological changes in the retail sector not only redesign work processes but also have wide-ranging implications for education, skills development, and policy-making. Therefore, to succeed in this transition, organizations must pay particular attention to human capital, continuous learning, and fostering a culture of innovation.

In summary, digital transformation strategies provide a comprehensive framework that integrates modern technologies, organizational change, and social dimensions, ensuring a sustainable path to organizational development and competitiveness.

Supply Chain

A supply chain is defined as a network of activities, resources, and information flows aimed at creating customer value and delivering products or services at the right time and place. In the era of Industry 4.0, supply chains have been significantly influenced by digital technologies, giving rise to the concept of the "smart supply chain" or "Supply Chain 4.0."

Núñez-Merino et al. (2022), through a systematic study, demonstrated that implementing new technologies such as IoT, big data, and AI plays a key role in transforming supply chains, elevating them from traditional processes to dynamic and predictive systems.

One of the main challenges in the digital supply chain is managing complexity and the associated risks. Nowzari et al. (2021), focusing on the use of IoT in Supply Chain 4.0, highlight that organizations face multiple barriers, including high costs, lack of unified standards, and security issues. This underscores the necessity of designing risk management and resilience strategies in the supply chain. Similarly, Jagtap et al. (2020) argue that Logistics 4.0 creates new opportunities such as optimizing goods flow and enhancing transparency, but it also brings technical and infrastructure challenges.

AI and machine learning are recognized as powerful tools for supply chain management. Numerous studies show that these technologies can improve demand forecasting, inventory management, and

transportation route optimization (Servos et al., 2019; Tang, 2022). For example, Jackson et al. (2024) demonstrated that using natural language processing to model logistics simulations makes the design and management of transportation systems more efficient. These findings highlight the growing importance of integrating modern technologies with supply chain management.

From a strategic perspective, the role of logistics and supply chains in the era of Industry 4.0 has become more critical than ever. Tang and Veelenturf (2019) emphasize that logistics is not merely an operational task but a strategic element for value creation and maintaining organizational competitiveness. García-Reyes et al. (2022) also affirm that organizations must improve their digital maturity levels to transform into Supply Chain 4.0.

Therefore, the modern supply chain is no longer a linear system but a dynamic and technology-driven network that combines technology, data, and strategy to serve as a powerful engine for organizational development.

Innovation Management

Innovation management is the process by which organizations identify, develop, and implement new ideas to improve products, services, and processes. In the digital era, innovation has become more dependent than ever on advanced technologies such as AI and big data.

Merhi and Harfouche (2023) argue that the successful adoption and implementation of AI in production systems requires key enablers such as a supportive organizational culture, technological infrastructure, and effective knowledge management. These factors ensure that technological innovation is not perceived as a one-time change but is institutionalized as a sustainable organizational capability.

Within the innovation management literature, the concept of "disruptive innovation" holds special significance. Hendriksen (2023) notes that the introduction of AI into supply chain management can be viewed both as a disruptive innovation and as a constructive change. In other words, while some technologies may disrupt traditional structures, they simultaneously create opportunities for generating new value. This duality requires managers to adopt a flexible and forward-looking approach to innovation management.

Knowledge management is one of the key mediating factors in effectively leveraging innovation. Leoni et al. (2022) demonstrated that knowledge management processes play a mediating role in the effective use of AI in manufacturing firms. This means that merely having access to technology is not enough; the organization's ability to learn, share, and apply knowledge determines the success of innovation. In this regard, Kaur et al. (2020) also state that changes in data-driven marketing strategies will succeed only if knowledge management consistently supports innovation.

From a market perspective, innovation not only improves internal organizational performance but also enhances customer experience. Pantano and Scarpi (2022) show that different forms of AI can influence customer emotions, creating emotional value and increasing brand loyalty. Similarly, Kumar et al. (2023) highlight the role of tools such as ChatGPT in managerial decision-making, demonstrating how these tools can facilitate innovation in customer interaction and market analysis.

Therefore, in the digital age, innovation management is a multidimensional approach that influences both the internal operations of organizations and their external interactions.

Technological Risk

Technological risk refers to a set of uncertainties and threats that arise from the development, implementation, or use of new technologies. These risks may include cybersecurity issues, system failures, lack of standardized protocols, and even social and ethical consequences. Hassel and Özkiziltan (2023) note that risks associated with artificial intelligence (AI) encompass not only technical dimensions but also socio-political aspects, requiring policy-making and oversight by governments and labor unions. This highlights that technological risk is a multidimensional concept that necessitates collaboration among various stakeholders.

One of the most critical dimensions of technological risk in the supply chain is managing disruptions caused by emerging technologies. Hejazi et al. (2022) demonstrated that although AI and payment flexibility can enhance companies' operational performance, these benefits cannot be realized without proper supply chain risk management. Similarly, Reyes et al. (2020) emphasize that dynamic management of new technologies in the global supply chain requires a thorough understanding of risks associated with technological innovations. Therefore, organizations must design comprehensive risk management frameworks to prevent potential crises and disruptions.

From a human resources perspective, technological risk also has significant implications. Hosseini Dahshiri and Aghaei (2019), by identifying and prioritizing human resource risks, showed that technological changes can lead to challenges such as the need for new skills, reduced job security, and increased psychological pressures on employees. These findings underscore the importance of training, reskilling, and change management as integral components of technological risk mitigation strategies.

Finally, technological risk is particularly pronounced in data- and AI-related domains, especially within service and retail industries. Padilla-Vega et al. (2023) warn that inadequate implementation of cybersecurity governance can cause irreparable damage to organizations. Likewise, Rathore et al. (2022) highlight barriers to the adoption of disruptive technologies in the logistics sector, noting that organizations must consider not only the potential benefits but also the possible threats of these technologies. In summary, technological risk is not merely a threat but an unavoidable reality, and its effective management can pave the way for sustainable competitive advantage.

Research Methods

The present study is classified as an applied research in terms of its objective, and based on the method of data collection, it falls within the descriptive research category, specifically of the survey type. Accordingly, the study first examines the aspects and topics related to the subject, as well as previous similar studies and research conducted on the topic. Subsequently, field studies are used to formulate hypotheses in line with the title and objectives of the research. Considering the four approaches in theorizing—namely, expanding or improving existing theories, comparing different theoretical perspectives, examining a specific phenomenon using various theoretical viewpoints, and investigating a documented and recurring phenomenon in a new environment and context—the present study is classified under the fourth approach. In this research, the Structural Equation Modeling (SEM) method and SmartPLS software were used to test the hypotheses. The statistical population of the study consisted of experts and specialists from the Mazandaran Boiler and Pressure Vessel Industry, totaling approximately 120 individuals. Due to the limited size of the population, no sampling was conducted, and a census approach was applied.

Data analysis

At this stage, in order to evaluate the conceptual model of the study and to ensure the existence or absence of causal relationships among the research variables, as well as to assess the fit of the observed data with the conceptual model, the research hypotheses were tested using Structural Equation Modeling (SEM). The results of the hypothesis tests are reflected in the following figures:

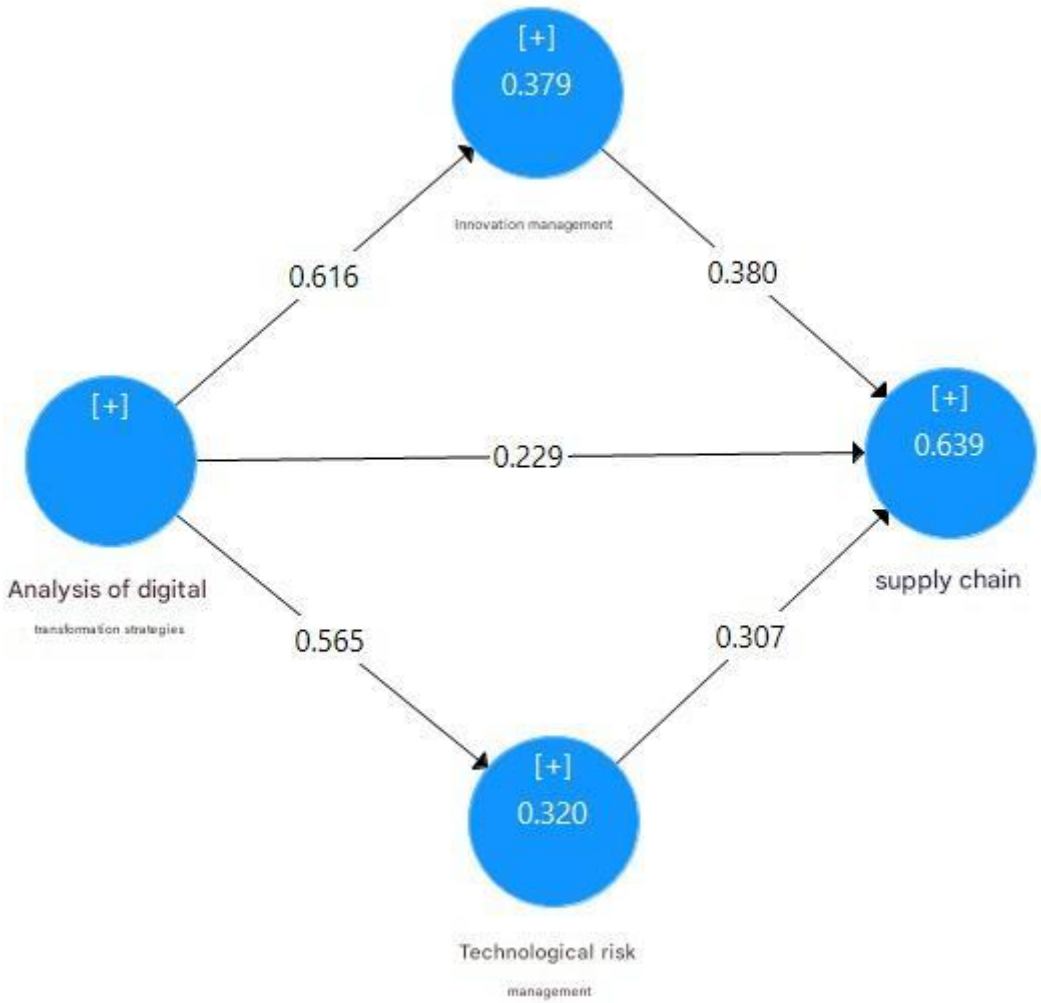

Figure 1: Measurement of the overall model and hypothesis results in the standardized state

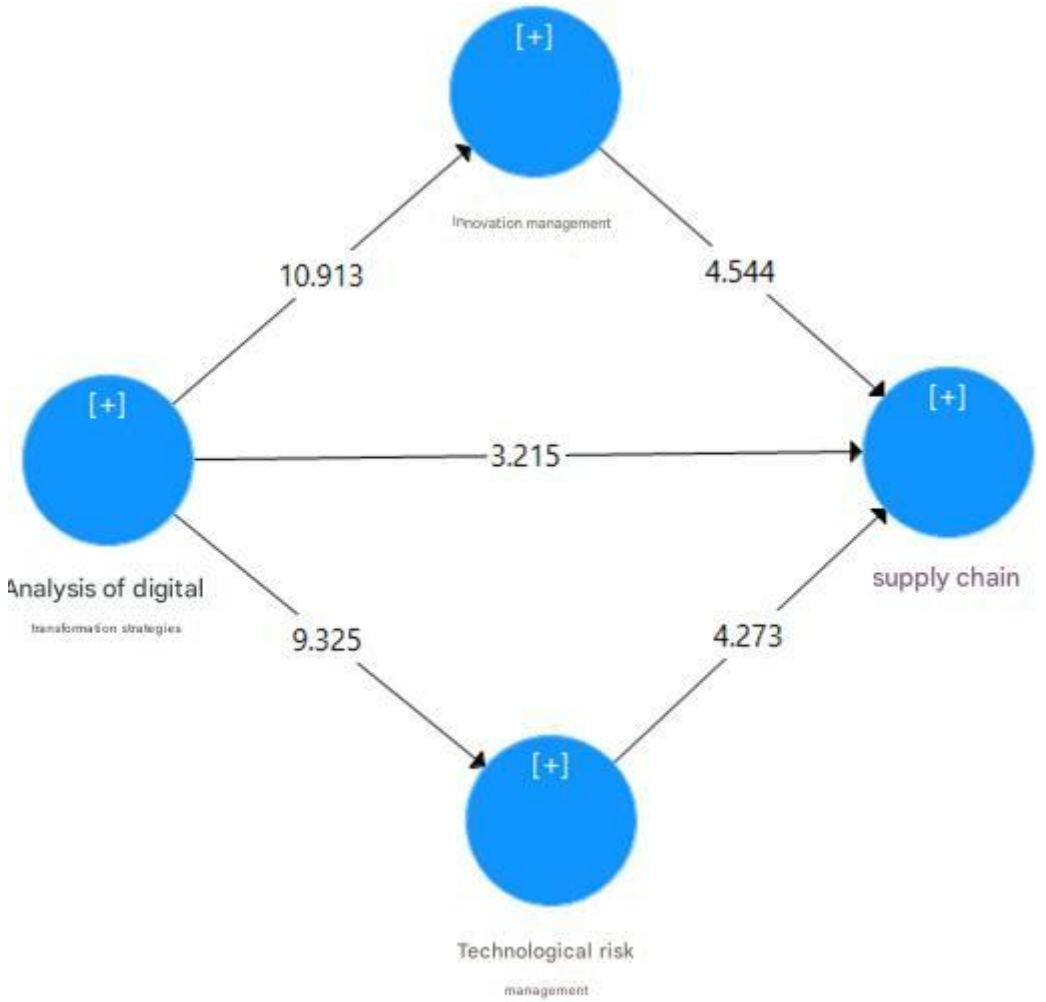

Figure 2: Measurement of the overall model and hypothesis results in the significant state

To assess reliability, Cronbach's alpha and composite reliability were used. Convergent validity was employed to evaluate validity, and the GOF index was used to assess model fit:

Table 1: Reliability and validity of the outer models

Fornell and Larker matrix				MSV	AVE	CR	◦ Variable
4	3	2	1				
			0.743	0.193	0.552	0.787	Analysis of digital transformation strategies
		0.803	0.342	0.478	0.644	0.844	Innovation Management
	0.807	0.477	0.331	0.423	0.651	0.918	Technological Risk Management
0.849	0.65	0.692	0.44	0.478	0.721	0.885	Supply chain

A Cronbach's alpha value above 0.7 indicates acceptable reliability.

A CR (Composite Reliability) value above 0.7 for each construct signifies adequate internal consistency for the measurement model.

An AVE (Average Variance Extracted) value above 0.5 indicates acceptable convergent validity.

Considering the GOF (Goodness of Fit) thresholds of 0.01, 0.25, and 0.36 for weak, moderate, and strong fit respectively, a value of 0.62 indicates a strong model fit.

The table below summarizes the significance coefficients and the results of the proposed hypotheses:

Table 2: Hypothesis Results

Result	Meaningfulness	Standard	Hypotheses
Confirmation	10.91	0.61	Analysis of digital transformation strategies has a positive and significant impact on innovation management.
Confirmation	9.32	0.56	Analysis of digital transformation strategies has a positive and significant impact on technological risk management.
Confirmation	3.21	0.22	Analysis of digital transformation strategies has a positive and significant impact on the supply chain.
Confirmation	4.54	0.38	Innovation management has a positive and significant impact on the supply chain.
Confirmation	4.27	0.30	Technological risk management has a positive and significant impact on the supply chain.

In Hypothesis 1, the study proposed that the analysis of digital transformation strategies has a positive and significant effect on innovation management. Statistical analysis between these two variables, as shown in Table 2, indicates that the significance value of the path between the variables is greater than 1.96. Therefore, this hypothesis is supported. Moreover, since the obtained significance value is positive, this effect is direct.

In Hypothesis 2, the study proposed that the analysis of digital transformation strategies has a positive and significant effect on technological risk management. Statistical analysis between these two variables, as shown in Table 2, indicates that the significance value of the path between the variables is greater than 1.96. Therefore, this hypothesis is supported. Furthermore, the positive significance value indicates a direct effect.

In Hypothesis 3, the study proposed that the analysis of digital transformation strategies has a positive and significant effect on the supply chain. Statistical analysis between these two variables, as shown in Table 2, indicates that the significance value of the path between the variables is greater than 1.96. Therefore, this hypothesis is supported, and the positive significance value shows that the effect is direct.

In Hypothesis 4, the study proposed that innovation management has a positive and significant effect on the supply chain. Statistical analysis between these two variables, as shown in Table 2, indicates that the significance value of the path between the variables is greater than 1.96. Therefore, this hypothesis is supported, and the positive significance value indicates a direct effect.

In Hypothesis 5, the study proposed that technological risk management has a positive and significant effect on the supply chain. Statistical analysis between these two variables, as shown in Table 2, indicates that the significance value of the path between the variables is greater than 1.96. Therefore, this hypothesis is supported, and the positive significance value shows that the effect is direct.

Conclusions

Based on the findings of the present study, the digital transformation strategies in the supply chain of the boiler and pressure vessel industry were analyzed from the perspective of innovation management and technological risk management. The results obtained from the collected data, analyzed using SPSS and SmartPLS software on the questionnaires, indicate the following:

1. Impact on Innovation Management: The research findings showed that the analysis of digital transformation strategies has a positive and significant effect on innovation management. This confirms

that digital technologies, including artificial intelligence, the Internet of Things, and big data, provide a suitable platform for generating new ideas, developing products and services, and revising organizational processes. In other words, digitalization not only accelerates information flow and reduces human error but also enhances organizational innovation capacity by creating dynamic knowledge networks. In the boiler and pressure vessel industry, where global competition and safety requirements are critical, adopting digital transformation strategies allows companies to identify innovative opportunities more rapidly and implement them efficiently. Therefore, it can be concluded that achieving sustainable and competitive innovation is difficult without leveraging digital approaches.

2. Impact on Technological Risk Management: The findings revealed that the analysis of digital transformation strategies has a positive and significant effect on technological risk management. In complex and high-risk industries such as boilers and pressure vessels, multiple challenges exist, including technical failures, market volatility, and regulatory pressures. Digital transformation, by providing advanced analytical tools, intelligent simulations, and alert systems, can identify, evaluate, and control technological risks. In other words, digital technologies enable forecasting and scenario analysis, allowing managers to handle technological uncertainties more effectively. Thus, implementing digital transformation strategies acts as a protective shield against technological risks and enhances organizational resilience under turbulent conditions.

3. Impact on Supply Chain Performance: The results indicated that the analysis of digital transformation strategies positively and significantly affects supply chain performance. Modern supply chains cannot respond to market needs relying solely on traditional relationships and require agility and flexibility for survival. Digital technologies, by providing a 360-degree view of material, information, and capital flows, enhance transparency and coordination among supply chain actors. In the boiler and pressure vessel industry, this is particularly important due to the critical role of specialized raw materials, strict safety standards, and precise production scheduling. Digital strategy analysis, using real-time data, inventory tracking, and improved decision-making, reduces costs, enhances service quality, and increases customer satisfaction. Therefore, digital transformation is a key driver for improving supply chain efficiency and competitiveness.

4. Impact of Innovation Management on Supply Chain: Findings showed that innovation management has a positive and significant effect on the supply chain. Innovation, whether in product development, processes, or business models, can improve productivity, reduce costs, and increase supply chain flexibility. Technological innovations enable the use of new materials, safer designs, and more efficient production methods. Additionally, innovation in collaboration models with suppliers and customers can improve coordination and synergy across the supply chain. In the boiler and pressure vessel industry, innovation in design and quality control not only increases safety and customer trust but also enhances competitiveness in international markets. Therefore, innovation acts as a driving force, transforming the supply chain from a traditional network into a dynamic, value-creating system.

5. Impact of Technological Risk Management on Supply Chain: The results indicated that technological risk management positively and significantly affects supply chain performance. Supply chains constantly face uncertainties and technological threats, ranging from raw material price fluctuations to production system disruptions and technological changes. Technological risk management, by identifying threats early and developing mitigation strategies, strengthens the sustainability and resilience of the supply chain. In the boiler and pressure vessel industry, any technological failure can have serious safety and economic consequences. Therefore, an effective technological risk management system plays a key role in reducing vulnerabilities and ensuring continuous production and distribution. From this perspective, technological risk management is a vital component that enhances trust, efficiency, and stability within the supply chain.

Overall Summary:

The overall findings indicate that the analysis of digital transformation strategies is not only a key factor in improving organizational performance but also serves as an intermediary link between innovation, technological risk management, and supply chain improvement. The confirmation of the hypotheses suggests that digital approaches, by providing intelligent, data-driven infrastructures, create a suitable platform for fostering innovation management and enhancing creative processes while enabling the identification, assessment, and control of technological risks. This helps organizations increase flexibility and agility in their supply chains while making more informed decisions, resulting in a sustainable competitive advantage. The findings also show that both innovation management and technological risk management play mediating and reinforcing roles in enhancing supply chain performance, where innovation increases value creation and differentiation in products and services, and technological risk management ensures sustainability and reduces supply chain vulnerability. Therefore, combining digital transformation with innovative mechanisms and technological risk management strategies creates a comprehensive and integrated model for supply chain development and enhancement, which not only improves efficiency and reduces costs but also significantly enhances resilience, flexibility, and organizational competitiveness.

Practical and Managerial Recommendations:

Based on the findings, several practical and managerial recommendations for managers in the boiler and pressure vessel industry are proposed:

1. Since digital transformation strategies positively and significantly impact innovation management, managers are advised to invest purposefully in digital technologies (e.g., IoT, AI, and big data analytics) to create an environment conducive to the development of creative and innovative ideas. This can reduce R&D costs and accelerate the commercialization of innovations.
2. The findings showed that digital transformation strategies influence technological risk management. Accordingly, companies are recommended to use data-driven predictive tools to identify technological threats and opportunities. This not only reduces uncertainty but also strengthens the organization's ability to respond quickly to technological risks.
3. The positive effect of digital transformation strategies on the supply chain indicates that digital technologies should be implemented integrally across the entire supply chain, from raw material procurement to product distribution. In particular, blockchain for transaction transparency and intelligent ERP and SCM systems for information synergy among supply chain actors are recommended.
4. Given the effective role of innovation management in improving supply chain performance, managers are advised to integrate innovation and technology development units as an essential part of supply chain strategies. This can lead to differentiated products, increased flexibility, and faster response to customer needs.
5. Since technological risk management positively affects the supply chain, companies are recommended to implement early warning systems and risk scenario planning within the supply chain structure. This will increase resilience, reduce operational disruptions, and improve predictability of material and information flows.

Overall, managers are advised to design and implement a comprehensive digital transformation roadmap focusing simultaneously on innovation, risk management, and supply chain enhancement, as the interaction of these three areas can provide a sustainable competitive advantage for the organization.

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