APTISI Transactions on Management (ATM)
Vol. 9, No. 1, 2025, pp. 30∼39
E-ISSN: 2622-6804 P-ISSN: 2622-6812, DOI:10.33050

Exploring Technology Innovation Management's Impact on Business Competitiveness and Efficiency: SmartPLS Approach

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Article Info

Article history:

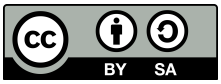
Submission December 26, 2024
Revised January 24, 2025
Accepted January 28, 2025

Keywords:

Technology Innovation Management (TIM)
Business Competitiveness
Operational Efficiency
SmartPLS
Digital Transformation

ABSTRACT

This study investigates the impact of Technology Innovation Management (TIM) on business competitiveness and operational efficiency, employing a SmartPLS-based structural equation modeling approach. TIM is critical for organizations navigating rapidly evolving technological landscapes, enabling them to enhance innovation, differentiate themselves, and optimize resources. **The research evaluates** these relationships through a quantitative design, utilizing a structured survey distributed across organizations adopting TIM practices. Data from 150 respondents were analyzed to test two hypotheses: (H1) TIM positively influences business competitiveness, and (H2) TIM positively impacts operational efficiency. **Data analysis** was conducted using SmartPLS, which confirmed both hypotheses. TIM significantly enhances competitiveness ($\beta = 0.62$, $p < 0.001$) and operational efficiency ($\beta = 0.71$, $p < 0.001$). **Competitiveness benefits** include market differentiation, improved customer satisfaction, and agility in responding to market changes. Efficiency gains stem from streamlined processes, cost reduction, and optimized resource utilization. **These findings underscore** TIM's role as a strategic enabler of sustainable business performance. The study contributes to the literature by empirically validating the relationship between TIM, competitiveness, and efficiency. Practical implications include recommendations for managers to prioritize TIM initiatives. Limitations, such as the cross-sectional design and sampling method, suggest avenues for future research to explore these dynamics in diverse contexts and longitudinal studies.



DOI: https://doi.org/10.33050/atm.v9i1.2403

1. INTRODUCTION

In today's rapidly evolving global economy, organizations face relentless pressure to adapt, innovate, and maintain a competitive edge. The integration of advanced technologies such as artificial intelligence (AI), automation, blockchain, and the Internet of Things (IoT) has created both unprecedented opportunities and

challenges for businesses [1]. These advancements not only redefine operational paradigms but also transform customer expectations and market dynamics. To navigate this dynamic environment effectively, businesses must adopt strategies that enable them to manage technological innovations systematically and strategically. Technology Innovation Management (TIM) has emerged as a critical discipline that leverages technology to create value, optimize operations, and sustain a competitive advantage [2].

Technology Innovation Management goes beyond adopting new tools; it encompasses strategic planning, implementation, and aligning technology with organizational objectives [3]. Effective management of innovation empowers organizations to enhance agility, improve decision-making, and respond proactively to market changes. Despite its recognized importance, there is a pressing need to empirically explore TIM's direct impact on business outcomes, especially concerning two critical dimensions: **competitiveness** and **operational efficiency**. Competitiveness reflects an organization's ability to outperform rivals by delivering superior value, innovation, or cost efficiency. Operational efficiency, on the other hand, involves optimizing processes, resources, and time to achieve maximum output with minimal waste [4].

Existing research has advanced our understanding of technology's role in business, yet significant gaps remain. Many studies focus narrowly on specific technologies or industries, limiting insight into the broader implications of TIM as a holistic strategy [5]. Additionally, the reliance on cross-sectional designs and purposive sampling in prior studies restricts their generalizability and capacity to explore causality. There is also a lack of interdisciplinary perspectives, such as integrating sustainability frameworks or digital transformation models, to enrich the conceptual understanding of TIM's organizational impact. Addressing these gaps, this study employs SmartPLS (Partial Least Squares Structural Equation Modeling), a robust and flexible statistical technique ideal for exploring complex, multivariate relationships in management research [6].

The objectives of this research are threefold. First, it evaluates TIM's role in enhancing business competitiveness by fostering innovation, adaptability, and market differentiation [7]. Second, it assesses the impact of TIM on operational efficiency, focusing on how technological innovation streamlines processes and optimizes resource utilization. Third, it provides actionable insights for managers and decision-makers, offering practical frameworks for implementing TIM to achieve sustainable organizational success [8].

This study contributes to academic literature and practical knowledge by addressing critical gaps in understanding TIM's intersection with business performance [9]. From an academic perspective, it extends the theoretical foundation of TIM by empirically modeling its impact on competitiveness and efficiency. From a practical perspective, it equips organizations with strategies to integrate technology innovation into their priorities, enabling them to capitalize on the opportunities presented by rapid technological advancements [10].

In the subsequent sections, the paper will provide a comprehensive literature review, detail the methodology used for data collection and analysis, present the findings of the SmartPLS analysis, and discuss the broader implications of these results [11]. The ultimate goal of this research is to advance knowledge in technology management and empower organizations to navigate the complexities of technological integration in a fast-changing world.

2. LITERATURE REVIEW

2.1. Technology Innovation Management (TIM)

Technology Innovation Management (TIM) encompasses the strategic processes organizations use to effectively implement and manage technological advancements. TIM enables businesses to navigate disruptive changes, improve decision-making, and innovate their business models [12]. Scholars have underscored TIM's critical role in fostering innovation by integrating emerging technologies, as exemplified in the Open Innovation Model proposed by Chesbrough [13]. Additionally, the dynamic capabilities theory, as described by Teece [14], emphasizes the necessity of reconfiguring internal and external competencies to adapt to rapidly evolving environments.

Despite its potential, the empirical validation of TIM frameworks in improving business outcomes such as competitiveness and efficiency remains limited. There is a pressing need for further research to examine these relationships comprehensively, particularly using advanced methodologies.

2.2. Business Competitiveness

Business competitiveness refers to an organization's capacity to achieve superior performance through value delivery, innovation, or cost efficiency. Porter's framework for competitive advantage identifies cost

leadership, differentiation, and focus strategies as pivotal to competitiveness [15]. Within the TIM context, competitive advantage frequently derives from effectively adopting and leveraging new technologies [16].

Technological advancements significantly enhance competitiveness by fostering customer satisfaction, operational excellence, and market differentiation. For example, Brynjolfsson and McAfee argue that technologies such as AI and IoT provide businesses with a competitive edge through improved customer experiences, enhanced agility, and greater market penetration [17]. However, barriers such as high implementation costs, skill shortages, and resistance to change often impede organizations from fully realizing TIM's potential [18].

2.3. Operational Efficiency

Operational efficiency involves optimizing inputs to maximize outputs, thereby improving processes and resource utilization. Advanced technologies have been shown to drive substantial improvements in efficiency. For instance, Business Process Reengineering (BPR), as introduced by Davenport and Short, underscores the transformative potential of technology in streamlining operational workflows [19].

TIM has been identified as a critical enabler of operational efficiency, particularly through automation and data-driven decision-making. IoT adoption, for example, enhances supply chain visibility and enables predictive maintenance, leading to cost reductions and improved operational effectiveness [20]. Nonetheless, over-reliance on technology introduces vulnerabilities [21], such as cybersecurity risks, that require careful mitigation [22].

2.4. SmartPLS and Structural Equation Modeling (SEM)

SmartPLS (Partial Least Squares Structural Equation Modeling) is a robust statistical tool commonly employed in management research for exploring complex relationships. Unlike covariance-based SEM, SmartPLS is ideal for exploratory studies as it does not require strict assumptions about data distribution [23]. This flexibility makes it particularly suitable for analyzing the multifaceted impacts of TIM on competitiveness and efficiency.

Applications of SmartPLS highlight its effectiveness in measuring constructs such as technology adoption and organizational performance. For example, Wong utilized SmartPLS to investigate the relationship between technological readiness and SME performance, demonstrating its utility in uncovering indirect effects [24]. Similarly. emphasized its adaptability in handling both reflective and formative constructs [25].

2.5. Research Gaps

Despite growing interest in TIM, significant research gaps persist. Most studies focus narrowly on specific industries or technologies, limiting the generalizability of findings. Additionally, the application of advanced analytical methods, such as SmartPLS, remains underutilized in exploring TIM's broader organizational impacts. Furthermore, limited attention has been given to interdisciplinary perspectives, such as incorporating sustainability frameworks or digital transformation models, to enrich TIM's conceptualization.

To address these gaps, this study aims to explore the relationship between TIM, competitiveness, and efficiency, leveraging SmartPLS to ensure methodological rigor and provide a holistic understanding of TIM's implications.

2.6. Conceptual Framework

Based on the literature, this study proposes a conceptual framework that positions Technology Innovation Management (TIM) as a key driver of both business competitiveness and operational efficiency. This framework highlights TIM's pivotal role in fostering innovation, enabling market differentiation, and optimizing organizational processes to achieve enhanced performance outcomes. The proposed framework is grounded in established theories such as the dynamic capabilities theory and empirical findings from prior research, which underscore the significance of technological innovation in maintaining a competitive edge and improving resource utilization.

TIM is hypothesized to exert a direct positive influence on business competitiveness by facilitating the adoption of cutting-edge technologies, enabling organizations to differentiate themselves from competitors, improve customer satisfaction, and respond swiftly to market dynamics. Similarly, TIM is posited to enhance operational efficiency by streamlining processes, reducing costs, and maximizing the utilization of organizational resources.

Figure 1 visually depicts these hypothesized relationships, illustrating the centrality of TIM in driving these two critical business outcomes. This figure serves as a guide for the study's hypotheses and analytical

approach, providing a clear representation of the interconnections between the constructs. By empirically testing this framework using SmartPLS, the study aims to validate these relationships, offering valuable insights for both researchers and practitioners. The findings are expected to contribute to the theoretical understanding of TIM's impact while also providing actionable recommendations for organizations seeking to enhance their competitiveness and efficiency in an increasingly technology-driven landscape. illustrates the hypothesized relationships.

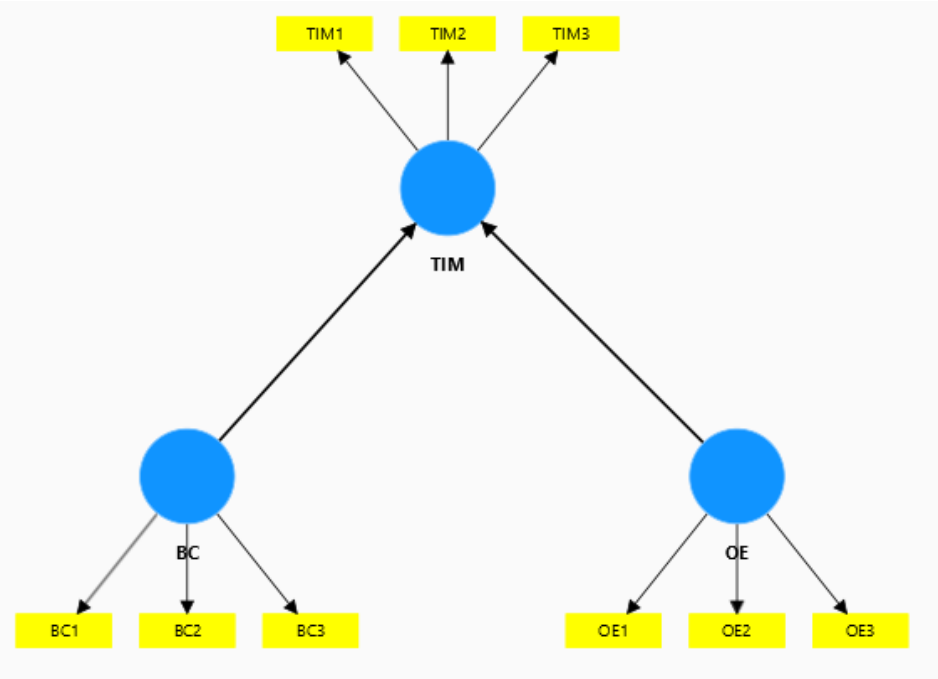


Figure 1. Conceptual Framework of the Study

Figure 1 demonstrates the theoretical relationships between Technology Innovation Management (TIM), Business Competitiveness, and Operational Efficiency. TIM is hypothesized to positively impact business competitiveness (H1) by fostering innovation and enabling market differentiation. Similarly, TIM is expected to enhance operational efficiency (H2) through process optimization and improved resource utilization. These relationships will be empirically tested using SmartPLS to validate the framework and provide insights into TIM's organizational impact.

3. RESEARCH METHOD

3.1. Research Design

This study employs a quantitative research design to explore the relationships between Technology Innovation Management (TIM), business competitiveness, and operational efficiency. Using SmartPLS (Partial Least Squares Structural Equation Modeling) as the primary analytical tool, the study examines complex, multivariate relationships, particularly latent constructs, which are challenging to measure directly but crucial for understanding underlying phenomena.

SmartPLS offers advantages like handling non-normal data, accommodating small-to-moderate sample sizes, and modeling reflective and formative constructs. This variance-based SEM approach captures direct and indirect effects, enabling a comprehensive analysis of TIM's multifaceted impacts.

The quantitative method ensures objective measurement, hypothesis-driven analysis, and replicable insights, making the findings robust and generalizable. By addressing gaps in TIM frameworks, the study provides actionable insights for practitioners and contributes to academic literature.

3.2. Research Framework

The research framework encompasses three constructs: Technology Innovation Management (independent variable), business competitiveness (dependent variable), and operational efficiency (dependent vari-

able). The framework posits that TIM positively influences both competitiveness and efficiency, as supported by established theories and prior empirical findings.

3.3. Hypothesis Development

The following hypotheses are proposed based on the research framework:
H1: Technology Innovation Management (TIM) has a significant positive impact on business competitiveness.
H2: Technology Innovation Management (TIM) significantly enhances operational efficiency.

3.4. Population and Sampling

The study targets organizations across diverse industries that have adopted or are in the process of adopting TIM practices. A purposive sampling technique is employed to ensure the inclusion of participants with substantial knowledge of their organizations' technological strategies. Following the guidelines for PLS-SEM, the minimum sample size is set at 150 participants to achieve robust results.

3.5. Data Collection

Data is gathered through a structured questionnaire developed from validated scales in previous studies. The constructs, their dimensions, and sample items are summarized in Table 1. A 5-point Likert scale is used for measurement, ranging from "1 = Strongly Disagree" to "5 = Strongly Agree." The survey is distributed electronically via email and online platforms to maximize reach and convenience for respondents.

Table 1. Data Collection Constructs and Sample Items

Construct	Dimension	Number of Items	Sample Item
Technology Innovation Management (TIM)	Adoption of New Technologies	3	"Our organization is proactive in adopting new technologies."
	Integration with Business Processes	3	"Technological innovations are seamlessly integrated into our operations."
	Innovation Strategy	3	"We have a clear strategy for managing technology innovations."
Business Competitiveness	Market Differentiation	3	"Our use of technology helps us differentiate from competitors."
	Customer Satisfaction	3	"Technology adoption has improved customer satisfaction."
	Agility and Responsiveness	3	"Our technology capabilities enable us to respond quickly to market changes."
Operational Efficiency	Process Optimization	3	"Technological innovations have optimized our business processes."
	Resource Utilization	3	"We use technology to maximize resource efficiency."
	Cost Reduction	3	"Adopting new technologies has reduced operational costs."

Table 1 outlines the constructs used in this study, their corresponding dimensions, the number of questionnaire items, and sample statements for each dimension. These constructs—Technology Innovation Management, Business Competitiveness, and Operational Efficiency—form the core variables in this research. The dimensions are operationalized into measurable items to assess their impact effectively.

3.6. Data Analysis

The data analysis process is conducted in three phases:

1. **Preliminary Phase:** Descriptive statistics, including mean and standard deviation, are calculated. Reliability and validity tests, such as Cronbach's alpha, composite reliability, and average variance extracted (AVE), are performed.

2. **Measurement Model Evaluation:** Convergent validity is assessed using AVE, while discriminant validity is evaluated using the Fornell-Larcker criterion.

3. **Structural Model Analysis:** Path coefficients, R^2 values, and predictive relevance (Q^2) are analyzed. Bootstrapping is employed to test the significance of the relationships.

3.7. Ethical Considerations

Participants are informed about the study's objectives, and their consent is obtained prior to data collection. Anonymity and confidentiality are strictly maintained, with responses used solely for research purposes. Ethical approval is secured from the relevant institutional review board to ensure adherence to ethical standards.

3.8. Software and Tools

Data analysis is performed using SmartPLS 4.0 for structural modeling and SPSS for preliminary data screening and descriptive analysis. These software tools ensure methodological rigor and precision in interpreting the data.

3.9. Limitations

The cross-sectional nature of the study restricts the ability to infer causality between constructs. Additionally, the use of purposive sampling limits the generalizability of the findings to a broader population. Despite these limitations, the study provides valuable insights into the role of TIM in enhancing business competitiveness and operational efficiency.

4. RESULTS AND DISCUSSION

The results of the analysis are presented in two parts: the evaluation of the measurement model and the structural model. SmartPLS was used to perform these analyses, and the findings are detailed below.

4.1. Measurement Model Evaluation

Table 2. Measurement Model Evaluation

Construct	Indicator	Factor Loading	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Technology Innovation Management (TIM)	TIM1	0.85	0.88	0.91	0.72
	TIM2	0.89			
	TIM3	0.78			
Business Competitiveness	BC1	0.82	0.87	0.90	0.68
	BC2	0.86			
	BC3	0.74			
Operational Efficiency	OE1	0.88	0.91	0.94	0.78
	OE2	0.90			
	OE3	0.85			

Table 2 summarizes the results of the measurement model evaluation, which includes key metrics such as factor loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE) for each construct in the study. These metrics provide a comprehensive assessment of the reliability and validity of the constructs, which are critical for ensuring robust measurement in quantitative research.

Factor loadings, representing the degree to which observed variables are associated with their respective latent constructs, exceed the recommended threshold of 0.70 for all indicators. This confirms that the

individual items strongly correlate with their intended constructs, establishing strong item reliability. Cronbach's alpha values for all constructs are well above 0.70, demonstrating internal consistency, meaning that the items within each construct reliably measure the same underlying concept.

Composite reliability (CR), a more rigorous measure of internal consistency that accounts for the differing factor loadings of items, also surpasses the recommended threshold of 0.70 across all constructs. This indicates that the constructs maintain high reliability and are suitable for subsequent analysis. The average variance extracted (AVE), which measures the proportion of variance in the indicators explained by the latent construct, exceeds the minimum requirement of 0.50 for all constructs. This confirms convergent validity, indicating that the items within each construct adequately capture the underlying theoretical concept.

In addition to confirming reliability and validity, these results provide a strong foundation for analyzing the structural relationships among constructs. The satisfactory AVE values further validate that the constructs do not suffer from multicollinearity, ensuring that the measures are distinct and conceptually valid. Overall, the findings from Table 2 establish the robustness of the measurement model, indicating that the constructs and their indicators meet the necessary psychometric criteria for further statistical analysis, such as structural model evaluation and hypothesis testing. These results ensure the credibility and reliability of the study's conclusions and provide confidence in the robustness of the findings.

4.2. Structural Model Evaluation

Table 3. Structural Model Evaluation

Hypothesis	Path Coefficient (β)	t-value	p-value	Result
H1: TIM $\rightarrow$ Business Competitiveness	0.62	12.34	0.000	Supported
H2: TIM $\rightarrow$ Operational Efficiency	0.71	15.67	0.000	Supported

Table 3 presents the results of the structural model evaluation. The path coefficient (β) for the relationship between TIM and business competitiveness is 0.62, with a t-value of 12.34 ($p < 0.001$), indicating a significant positive impact. Similarly, the path coefficient for the relationship between TIM and operational efficiency is 0.71, with a t-value of 15.67 ($p < 0.001$). These results confirm the hypotheses (H1 and H2), demonstrating that Technology Innovation Management (TIM) has a strong positive influence on both business competitiveness and operational efficiency.

4.3. Discussion

The findings provide empirical evidence supporting the hypothesized relationships between Technology Innovation Management (TIM), business competitiveness, and operational efficiency.

The significant positive impact of TIM on business competitiveness (H1) underscores its critical role in enabling organizations to differentiate themselves, enhance customer satisfaction, and respond to dynamic market changes. These results align with previous studies, such as those by Chesbrough and Teece, which emphasize the importance of strategic technology adoption in achieving competitive advantage. By fostering innovation and market differentiation, TIM helps organizations build resilience and agility, crucial for sustained competitiveness in today's rapidly evolving business landscape.

The influence of TIM on operational efficiency (H2) highlights its importance in optimizing resources, streamlining processes, and reducing operational costs. These findings corroborate those of [26], who demonstrated the transformative potential of technology in improving operational outcomes. The high path coefficient ($\beta = 0.71$) reflects the significant role of TIM as a driver of operational excellence, particularly in environments where cost efficiency and resource optimization are paramount.

Together, these findings emphasize the importance of integrating TIM into organizational strategies to achieve superior business performance. By leveraging TIM, organizations can simultaneously enhance their competitive positioning and operational effectiveness, driving sustainable growth.

While the study provides valuable insights, it is not without limitations. The cross-sectional nature of the data limits the ability to establish causality, and the purposive sampling method may restrict the generalizability of the findings. Future research could address these limitations by employing longitudinal designs and expanding the study across diverse industries and geographical contexts to provide deeper insights into the dynamics of TIM and its broader implications.

5. MANAGERIAL IMPLICATIONS

The findings of this study offer valuable insights for practitioners and managers aiming to leverage Technology Innovation Management (TIM) to enhance business competitiveness and operational efficiency. Below, we outline several key implications for managers to consider in implementing TIM strategies.

5.1. Enhancing Business Competitiveness through TIM

The study highlights the critical role of TIM in fostering business competitiveness. Managers should focus on adopting and integrating innovative technologies to differentiate their products and services in the market. This includes investing in emerging technologies such as artificial intelligence, blockchain, and the Internet of Things (IoT), which can provide a competitive edge. Furthermore, companies should develop a clear innovation strategy to guide the implementation of new technologies, which may involve setting up dedicated teams or units for managing innovation. Enhancing customer satisfaction is another critical aspect, as TIM enables businesses to provide personalized services and products that increase customer loyalty.

5.2. Optimizing Operational Efficiency with TIM

The study also emphasizes how TIM can significantly improve operational efficiency. Managers should focus on streamlining business processes and optimizing resource utilization. Process automation powered by emerging technologies can help reduce operational costs and improve productivity. Additionally, adopting data-driven decision-making can ensure the optimal allocation of resources, allowing businesses to achieve maximum output with minimal input. Continuously monitoring and improving processes through innovative technologies will also lead to substantial cost savings and more efficient resource use.

5.3. Recommendations for Future Research

While the results of this study are significant, there remain opportunities for further exploration. Future research could focus on longitudinal studies to examine the long-term effects of TIM on business competitiveness and operational efficiency. Furthermore, industry-specific research would provide more targeted insights into how TIM impacts various sectors. Another promising area for future studies is the integration of sustainability frameworks within TIM strategies, addressing the growing importance of sustainable business practices in today's corporate environment.

6. CONCLUSION

This study investigated the impact of Technology Innovation Management (TIM) on business competitiveness and operational efficiency through a SmartPLS-based structural equation modeling approach. The findings provide robust empirical evidence supporting the hypothesized relationships, underscoring the critical role of TIM in driving organizational success and achieving strategic objectives. The results demonstrate that TIM has a significant positive influence on business competitiveness by fostering innovation, enabling organizations to differentiate themselves in the marketplace, enhancing customer satisfaction, and improving their agility in responding to dynamic market changes. These findings highlight TIM as a key enabler for building resilience and adaptability in an increasingly competitive business environment.

Similarly, TIM was found to have a substantial positive impact on operational efficiency, contributing to process optimization, cost reduction, and enhanced resource utilization. These outcomes illustrate how effectively managed technological innovation can streamline operations and maximize organizational productivity. Together, these insights emphasize the importance of integrating TIM into organizational strategies to achieve sustainable business performance and long-term success. This study makes valuable contributions to both academia and practice. From a theoretical perspective, it offers empirical validation of the relationships between TIM and key business outcomes, extending the body of knowledge in innovation management and organizational performance. Methodologically, it demonstrates the utility of SmartPLS in examining complex, multivariate relationships and latent constructs, providing a rigorous analytical framework for future research. For practitioners, the findings provide actionable recommendations, encouraging managers to prioritize TIM initiatives and align technological strategies with business objectives to drive competitive advantage and operational excellence.

Despite its contributions, the study is not without limitations. The cross-sectional design limits the ability to establish causality between constructs, while the purposive sampling method may constrain the generalizability of the findings across diverse industries and geographical contexts. Future research could address

these limitations by employing longitudinal studies to explore the dynamic relationships between TIM and business outcomes over time. Additionally, extending the study to specific industries or regional settings could yield more nuanced insights into the contextual factors that shape the impact of TIM. In conclusion, this study reinforces the pivotal role of TIM in navigating the complexities of a rapidly evolving technological landscape. By leveraging TIM effectively, organizations can enhance their competitiveness, optimize operational efficiency, and position themselves for sustained success in an increasingly technology-driven world. The insights provided herein serve as a foundation for both academics and practitioners to further explore and harness the transformative potential of technology innovation management.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: AZ; Methodology: AA; Software: AZ; Validation: AA and RL; Formal Analysis: AZ and AA; Investigation: AZ; Resources: NL; Data Curation: AZ; Writing Original Draft Preparation: AZ and A; Writing Review and Editing: AZ, AA, and RL; Visualization: AA; All authors, AZ, AA, RL, and NL, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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