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HARNESSING KNOWLEDGE CULTURE - REDEFINING STRATEGIC INSIGHTS FOR EFFECTIVE TECHNOLOGY TRANSFER MODELS

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ABSTRACT

This study addresses the need to modernize technology transfer frameworks culture in evolving ecosystems. It examines how theoretical and practical frameworks, such as the Stage-Gate Process, Technology Readiness Levels (TRL), and ISO standards, contribute to the development of adaptive models. Additionally, it evaluates guidelines from WIPO, the European Commission, and NIST. Building on seminal works such as the Stage-Gate Process and TRL framework, the study incorporates perspectives from OECD and WIPO frameworks. A mixed-methods approach integrates theoretical analysis with case studies in biotechnology, renewable energy, and artificial intelligence. Empirical data assess NIST processes and ISO standards in innovation management. Findings emphasize the need to complement traditional models with adaptive methodologies. Integrating TRL with ISO standards enhances scalability and efficiency, while WIPO and OECD frameworks foster collaboration and commercialization. These findings underscore the necessity of hybrid models that leverage institutional guidelines and digital tools. As the study focuses on developed economies, its applicability to emerging markets may be limited. Nonetheless, it provides actionable insights for policymakers, academia, and industry, advocating adaptive frameworks to foster innovation and economic growth.

KEYWORDS: Innovation Management Culture, Technology Transfer Culture, Open Innovation Culture, Innovation Commercialization

1. INTRODUCTION

Technology transfer (TT) in the context of innovation management is increasingly recognized as a strategic driver that transforms scientific advancements into economically viable innovations, fostering competitive and sustainable economic growth [1]-[3]. However, the contemporary global innovation landscape is undergoing profound transformations-the rapid pace of technological development, digital transformation, and the growing demand for interdisciplinary and cross-sectoral collaboration are challenging traditional TT models [4]-[7]. Whereas established frameworks such as the Stage-Gate process and Technology Readiness Levels (TRL) have demonstrated their relevance across various industries, their effectiveness becomes questionable in sectors characterized by high technological dynamism, such as artificial intelligence, biotechnology, and renewable energy [8], [9].

The significance of this study lies in the urgent need to modernize technology transfer processes, developing more flexible and adaptive management models that align with the evolving demands of contemporary innovation ecosystems [10]. Currently, both academic and practical discourse is dominated by structured TT models, which, whereas systematic, often lack the necessary adaptability to effectively integrate into the multidimensional and continuously evolving landscape of technological development and commercialization [11]-[14].

The aim of this study is to develop future-oriented guidelines for enhanced technology transfer models in innovation management, enabling them to effectively respond to contemporary economic challenges whereas making a significant contribution to both the theory and practice of innovation management.

A critical analysis of the existing theoretical and practical frameworks of innovation management and TT models (state of the art) highlights key structural strengths and limitations. The Stage-Gate process stands out for its modular phase structure and clearly defined decision criteria, ensuring efficient risk management [15]. However, its overly linear and bureaucratic nature makes it ill-suited to support the dynamic and iterative nature of modern technology development environments [16], [17]. Similarly, the Technology Readiness Level (TRL) framework, originally developed by NASA, provides a structured assessment of technological progress. However, it lacks an integrated market dimension and business modeling approach, which are critical factors in determining commercial viability [18].

Recent institutional guidelines from WIPO [19], the European Commission [20], and NIST [21] provide a strategic and globally recognized framework for intellectual property management, innovation commercialization, and collaboration mechanisms. However, their effectiveness remains constrained, as they often lack the necessary flexibility to accommodate local and regional specificities and the varying institutional capacities across different innovation ecosystems [22].

The central research question of this study is: How can the integration of theoretical and practical frameworks-such as the Stage-Gate process, TRL, Lean, and Agile methodologies, along with WIPO, European Commission and NIST guidelines, as well as ISO standards-enhance the adaptability of technology transfer models in innovation management? The objective is to develop a more dynamic and flexible TT model that aligns with the evolving demands of contemporary innovation ecosystems, ensuring greater responsiveness to rapid technological advancements and market-driven innovation processes.

The hypothesis of this study posits that the integration of traditional technology transfer models with institutional guidelines and digital solutions significantly enhances the efficiency and scalability of TT processes in developed economies, thereby fostering sustainable innovation growth.

The study employs a mixed-methods approach, combining theoretical analysis with empirical case studies. The empirical research was conducted in Latvia from 2017 to 2024, utilizing an expert evaluation methodology. A total of 17 innovation and business development executives were interviewed across four key sectors: biotechnology, renewable energy, IT, and traditional food processing. The selected sectoral distribution ensures a representative and multidimensional analysis, making the findings both scientifically robust and applicable in a broader context.

The intensity of adaptive models was assessed based on expert evaluations from corporate executives, using a scale from 1 to 10-where 1 indicates minimal use of adaptive hybrid models (e.g., Agile, Lean Startup, Design Thinking), whereas 10 represents full and regular integration into daily innovation management processes.

Similarly, the intensity of institutional guideline implementation was evaluated using a 1 to 10 scale, reflecting the practical adoption of OECD/EK and WIPO guidelines in corporate strategic and daily innovation management. Lower scores indicate weak or infrequent integration, whereas higher scores

reflect systematic and regular application of these guidelines.

The commercialization success rate (%) was calculated as the proportion of successfully launched innovations relative to the total number of innovation projects initiated by each company. A successful innovation was defined as one that maintained commercial viability for at least 24 months post-market entry, generating positive economic returns for the company. This metric was quantified in percentage terms, based on data provided by corporate representatives.

These carefully established and rigorously defined parameters facilitated an in-depth and thorough analysis of the effectiveness of adaptive models and institutional guidelines across a wide range of business contexts in Latvia. This analysis not only enriched the scientific understanding of technology transfer processes but also provided valuable practical insights, ultimately contributing to the refinement and optimization of strategies aimed at enhancing the efficiency and effectiveness of technology transfer operations.

2. THE EVOLUTION OF TECHNOLOGY TRANSFER PROCESSES – THEORETICAL PARADIGMS AND PRACTICAL CHALLENGES

The evolution of technology transfer processes is closely linked to the transformation of broader innovation management paradigms over the past decades. The contemporary technological development landscape has shifted radically from structured and linear innovation methodologies to flexible, adaptive, and iterative models. This transition stems from the growing need for rapid adaptation to market dynamism, technological convergence, and the accelerated innovation cycle, requiring organizations to embrace more agile and responsive TT strategies.

One of the earliest widely recognized models in innovation management was the Booz, Allen & Hamilton (BAH) innovation development framework [23], which, in the second half of the 20th century, established standards for structuring the innovation process-from idea generation to commercial implementation. This model marked the beginning of systematic innovation management, providing a structured approach to technology transfer. However, its rigid sequential structure and high documentation intensity gradually became constraints, limiting flexibility and responsiveness in rapidly evolving innovation environments.

A critical turning point in innovation management was the Stage-Gate model [15]. This framework, which structures innovation management into sequential phases separated by decision "gates," serves as an effective risk and resource management tool. Its modular architecture ensures a clear and structured decision-making process, whereas also allowing for iterative refinements and adaptive adjustments. However, despite its enduring popularity, the inherent linearity of the Stage-Gate model can become a constraint in rapidly evolving and highly dynamic industries, where responsiveness and agility are critical for maintaining competitive advantage.

The Technology Readiness Level (TRL) framework, originally introduced by NASA, provides a structured approach for assessing technology maturity, progressing from conceptual stages to practical application [24]. TRL is notable for its simplicity and universal applicability across diverse technological domains, making it a widely adopted tool for evaluating technological feasibility. However, a critical limitation of the TRL model is its lack of integration with market, commercial, and user interaction dynamics. This omission creates a significant risk, where technologies may achieve high technical readiness but fail to attain market viability, ultimately limiting their successful commercialization.

In response to the limitations of linear models, the past two decades have witnessed a rapid rise in the adoption of Agile methodologies in innovation management [25]. Rooted in the information technology sector, Agile approaches emphasize an iterative process driven by continuous user feedback and adaptive development cycles. Complementing this, the Lean Startup methodology [26] and Design Thinking framework [27] integrate market validation and rapid prototyping principles, enhancing both efficiency and market alignment within the technology transfer process. These methodologies collectively foster a more dynamic, responsive, and market-driven approach, addressing the shortcomings of traditional, rigid innovation frameworks.

For the management of radical and disruptive innovation processes, Christensen's theories offer a compelling perspective on market paradigm shifts [28]. His framework emphasizes how low-initial-performance technologies gradually gain market dominance by fundamentally altering competitive dynamics and redefining industry standards. Disruptive innovation challenges incumbent market leaders, reshaping technological landscapes and accelerating nonlinear industry evolution. The discussed paradigms are summarized in Table I.

Table 1: Strategic Comparative Analysis of Technology Transfer Paradigms

Model	Core Principles	Advantages	Challenges	Industry Suitability
BAH	Linear structure, document-ation intensive process	Clearly defined and structured approach	Low flexibility, slow responsive-ness to dynamic environ-ments	Traditional industries
Stage-Gate	Modu-larity, iterative decision-making check-points	Effective risk manage-ment, structured innovation governance	Linear progression, bureaucratic complexity	Bio-technology, pharmaceu-ticals
TRL	Techno-logy readiness assessment framework	Simplicity, well-defined evaluation criteria	Lack of market and commercial integration	Aerospace, defense, advanced technology development
Agile, Lean Startup, Design Thinking	Flexibility, iterative cycles, market-driven validation	High adaptability, rapid innovation cycles	Challenging implementation in large, hierarchical organiza-tions	Artificial intelligence, software development
Disrup-tive Innova-tion	Market paradigm shifts, creation of new markets	High-impact potential, enables the emergence of new dominant players	High uncertainty, elevated risk exposure	Renewable energy, technology-driven disruptive industries

The strategic analysis of technology transfer paradigms reveals fundamental distinctions between various approaches to innovation commercialization and their sector-specific adaptability. Linear and structured models, such as BAH and Stage-Gate, provide clear process governance and risk mitigation mechanisms; however, their rigid hierarchies and bureaucratic constraints limit agility in dynamic markets.

Conversely, the TRL framework emphasizes technological maturity assessment but lacks integration with market and business dynamics, posing challenges for commercialization. In contrast, Agile, Lean Startup, and Design Thinking methodologies enable high adaptability and rapid market responsiveness, yet their implementation in large, hierarchical organizations is often met with structural resistance.

The disruptive innovation paradigm focuses on radical market transformation and the creation of entirely new industries. However, its inherent high risk and uncertainty necessitate a long-term strategic vision and the capability to navigate volatility effectively. This comparative assessment underscores the trade-offs between control, adaptability, and scalability, highlighting the growing need for hybrid, context**-specific models** in modern innovation ecosystems.

3. INSTITUTIONAL AND INTERNATIONAL FRAMEWORKS FOR ENHANCING TECHNOLOGY COMMERCIALIZATION

The global economy is increasingly characterized by interconnectivity, where technology commercialization processes are no longer confined to local or national scales. Instead, institutional and international frameworks serve as critical catalysts for technology commercialization, shaping both strategic principles and practical guidelines for technology transfer and market integration on a global scale. These frameworks provide regulatory coherence, intellectual property protection, and cross-border collaboration mechanisms, enabling firms and research institutions to navigate the complexities of international innovation ecosystems more effectively [29]-[31].

The WIPO guidelines for technology transfer emphasize three core pillars: technology commercialization strategies, intellectual property (IP) management, and international collaboration [19]. These guidelines highlight the strategic role of IP as a key instrument for ensuring legal clarity, attracting investment, and facilitating knowledge transfer in a global context. By providing a structured approach to IP governance, WIPO aims to enhance the efficiency and transparency of technology commercialization across diverse industries.

However, a critical challenge lies in the adaptability of these guidelines to regional and national infrastructural disparities, particularly in developing economies, where institutional capacity and legal frameworks for effective IP management are often insufficient or underdeveloped. This limitation underscores the need for context-sensitive adaptations to ensure that WIPO's principles remain effective and inclusive across varied innovation ecosystems.

The Organisation for Economic Co-operation and Development (OECD) and the European Commission (EC) complement the global technology transfer framework by providing recommendations that emphasize open innovation and public-private partnerships (PPP) [32]. These frameworks advocate for greater collaboration between academic institutions and industry, fostering interdisciplinary and cross-sectoral approaches to accelerate the translation of technological advancements into commercially viable products and services.

OECD guidelines particularly highlight the critical role of cooperation in bridging the gap between research and market application, facilitating more efficient knowledge flows within innovation ecosystems. Meanwhile, the European Commission's recommendations, such as the Code of Practice for Knowledge Transfer, extend the OECD framework by reinforcing transparency in intellectual property (IP) management and promoting effective licensing strategies [33], [34]. These measures aim to support both strategic industrial stakeholders and broader societal interests, ensuring that technology commercialization aligns with public and private sector needs in a sustainable and inclusive manner.

The National Institute of Standards and Technology (NIST) model in the United States complements existing international frameworks by offering a targeted approach to technology commercialization through public-private sector synergy [21]. NIST specifically highlights the Cooperative Research and Development Agreements (CRADA) as a key mechanism that effectively integrates the technological potential of government laboratories with industrial needs and resources [35]. CRADA provides clear legal and operational structures, outlining intellectual property (IP) rights, technology transfer conditions, and shared responsibilities for further technology development and commercialization. By formalizing collaborative innovation pathways, this model enhances the efficiency of knowledge exchange between public research institutions and industry.

However, a major challenge of the CRADA framework lies in its bureaucratic complexity and high administrative costs, which can hinder accessibility for smaller enterprises and fast-growing technology ventures. These constraints underscore the need for process optimization and increased flexibility to ensure that CRADA remains an effective tool for fostering technology-driven economic growth across diverse business environments. The discussed frameworks are summarized in Table II.

Table 2: Comparative Analysis of Institutional and International Frameworks in Technology Commercialization

Institution/Framework	Core Guidelines	Advantages	Challenges
WIPO	IP management, global licensing	Global standardiza-tion, international collaboration	Limited adaptability to developing economies
OECD & EC	Open innovation, PPP, transparency in IP management	Broad collaboration, effective knowledge governance	Variability in institutional capacity and resources across countries
NIST (CRADA)	Public-private synergy, well-defined legal frameworks	Effective IP governance, alignment with industrial needs	Bureaucratic complexity, high administrative costs

The comparative analysis of institutional and international frameworks highlights key mechanisms that influence the efficacy of innovation transfer across different contexts. WIPO provides a globally standardized approach to intellectual property (IP) management and international collaboration, fostering a harmonized regulatory environment. However, its lack of flexibility poses challenges for developing economies, where local innovation ecosystems often lack the necessary institutional infrastructure for effective IP governance. The OECD and European Commission (EC) frameworks promote open innovation principles and public-private partnerships (PPP), facilitating efficient knowledge flows and greater transparency in IP governance. However, disparities in economic and institutional capacity among countries frequently limit equal access to these mechanisms, leading to uneven commercialization outcomes. The NIST (CRADA) model, which emphasizes well-defined legal structures and public-private synergy, enhances IP protection and industrial applicability. Despite its effectiveness in aligning technological potential with industry needs, bureaucratic constraints and high administrative costs restrict accessibility for small enterprises and high-growth startups.

Institutional and international frameworks provide a fundamental foundation for effective global technology commercialization. However, each framework has critical limitations that require further adaptation and integration within local innovation ecosystem processes to ensure contextual relevance, operational efficiency, and sustained impact.

4. THE NEED FOR ADAPTIVE HYBRID MODELS IN TECHNOLOGY TRANSFER – THEORETICAL AND EMPIRICAL JUSTIFICATION

Traditional technology transfer models, such as Stage-Gate and TRL, struggle to adapt to the fast-evolving innovation landscape. Their rigid, linear structures limit responsiveness to dynamic market demands, technological convergence, and disruptive innovations. Additionally, they often neglect market-driven feedback loops, crucial for successful commercialization and user alignment.

To address these challenges, adaptive hybrid

models integrate structured risk management with flexible methodologies like Agile, Lean Startup, and Design Thinking. This fusion enhances responsiveness, iterative development, and market-driven adaptation. However, effective implementation requires a shift from rigid decision-making toward agile governance, cross-functional collaboration, and real-time adaptability.

A key framework supporting this transition is ISO 56000, which provides a structured yet flexible approach to innovation management. Its adaptability across industries helps organizations balance process discipline with flexibility, fostering continuous learning and long-term competitiveness. In Latvia, businesses actively leverage ISO 56000 to enhance innovation efficiency and commercialization success.

Empirical analysis (2017–2024) evaluated adaptive model integration across biotechnology, renewable energy, IT, and food processing sectors. Expert assessments (using a 1–10 scale) measured the extent of adaptive hybrid models and institutional framework implementation (OECD/EC, WIPO). The study found that higher adoption of adaptive models correlates with improved commercialization success, emphasizing the importance of institutional alignment and flexible methodologies for optimizing technology transfer processes.

The correlation analysis was conducted using the Pearson correlation coefficient to assess the relationship between the intensity of adaptive hybrid model adoption and innovation commercialization success. The Mentioned statistical approach enabled a quantitative evaluation of the degree to which the integration of adaptive methodologies influences the commercial viability of innovations, providing empirical insights into the effectiveness of flexible innovation management strategies in dynamic business environments. The correlation analysis results are summarized in Table III.

Table 3: Correlation Analysis – Intensity of Adaptive Hybrid Model Adoption and Innovation Commercialization Success in Latvia

Sector	Correlation Coefficient (r)	Statistical Significance (p-value)
Biotechnology	0.81	0.01
Renewable Energy	0.74	0.02
IT	0.79	0.015
Food Processing	0.62	0.03
Overall	0.78	<0.01

The correlation analysis between adaptive hybrid model adoption intensity and innovation commercialization success in Latvia provides compelling empirical evidence of these models' effectiveness. The high correlation coefficients across all sectors, particularly in biotechnology ($r = 0.81$, $p=0.01$) and IT ($r = 0.79$, $p = 0.015$), underscore the critical importance of dynamic approaches to technology transfer and commercialization, particularly in science- and technology-intensive industries. The renewable energy sector ($r = 0.74$, $p = 0.02$) exhibits a similar pattern, indicating that market fluctuations and regulatory challenges necessitate a high degree of adaptability. Conversely, the food processing sector's comparatively lower correlation ($r = 0.62$, $p = 0.03$) suggests that factors beyond adaptive model adoption-such as market traditions and consumer behaviour-may play a more significant role in innovation commercialization success. The overall correlation coefficient ($r = 0.78$, $p < 0.01$) strongly affirms that adaptive hybrid models enhance the successful market introduction of innovations by fostering organizational flexibility, rapid iteration, and efficient resource allocation. Findings further validate that the flexibility and adaptability of hybrid models are critical success factors in fast-paced and technologically complex innovation environments, reinforcing the need for enterprises to integrate adaptive frameworks into their technology transfer and commercialization strategies.

Given that NIST guidelines are not utilized in Latvia, they were excluded from the analysis. The empirical analysis of institutional guidelines in Latvia reveals a significant positive correlation between the adoption of OECD/EC and WIPO frameworks and innovation success, highlighting the critical role of institutional structures in shaping innovation ecosystems. The high correlation coefficient for OECD/EC guidelines ($r = 0.72$, $p < 0.01$) underscores their effectiveness in fostering knowledge transfer, intellectual property (IP) management, and public-private partnerships (PPP). The empirical findings are summarized in Table IV.

Table 4: Empirical Analysis of Institutional Guidelines – Implementation and Innovation Success in Latvia

Institutional Guideline	Correlation Coefficient (r)	Statistical Significance (p-value)
OECD/EC	0.72	<0.01
WIPO	0.65	<0.05

These findings validate that open innovation principles and governance transparency are key determinants of innovation success. The WIPO guidelines also exhibit a positive correlation ($r = 0.65$, $p < 0.05$), indicating that global IP management frameworks contribute to innovation commercialization success. However, the lower correlation compared to OECD/EC suggests that WIPO's influence on practical innovation governance in Latvia may be more limited, potentially due to challenges in adapting international IP strategies to the local business environment.

Overall, the implementation of OECD and WIPO guidelines demonstrates a substantial positive impact on innovation outcomes, reinforcing the importance of institutional frameworks in driving successful innovation management and commercialization processes.

The sectoral comparison of adaptive model and institutional guideline application in innovation commercialization in Latvia confirms that high-tech industries integrate both dynamic innovation management approaches and institutional frameworks more effectively, resulting in a higher commercialization success rate (28.4% vs. 17.2% in traditional industries). The adaptive model intensity score (8.1 vs. 6.3) suggests that technology-driven sectors exhibit a greater capacity for market adaptation, leveraging flexible innovation methodologies such as Agile, Lean Startup, and Design Thinking to navigate rapid technological advancements and shifting market demands. The sectoral comparison results are summarized in Table V.

Table 5: Sectoral Comparison – Application of Adaptive Models and Institutional Guidelines in High-Tech and Traditional Industries in Latvia

Sector Category	Adaptive Model Intensity	Institutional Guideline Intensity	Commercialization Success (%)
High-Tech Industries	8.1	7.8	28.4
Traditional Manufacturing Industries	6.3	5.4	17.2

Similarly, the institutional guideline intensity score (7.8 in high-tech vs. 5.4 in traditional industries) indicates that international innovation governance frameworks, such as OECD/EC and WIPO guidelines, are more systematically implemented in high-tech enterprises. This enables them to capitalize on global innovation ecosystems and maximize the impact of structured IP management and regulatory alignment. However, traditional industries, despite demonstrating a lower intensity in adaptive model adoption, still benefit significantly from their implementation, reinforcing the universal applicability of adaptive frameworks in innovation management. This underscores the need for broader integration of adaptive hybrid models across all industry segments to enhance innovation commercialization efficiency and economic impact.

The findings reveal that innovation commercialization success is driven not only by technological complexity but also by a company's ability to integrate both adaptive models and institutional guidelines. To enhance commercialization efficiency in traditional industries, further adoption of adaptive models and tailoring of institutional frameworks to address industry-specific challenges are essential. Such strategic adjustments could increase market success rates for innovations across these sectors, reinforcing the broader applicability of adaptive hybrid approaches.

The comparative analysis underscores those high-tech enterprises leverage both adaptive methodologies and institutional guidelines more intensively, resulting in substantially higher innovation commercialization success rates. While traditional industries exhibit lower adoption intensity, they still derive significant benefits from integrating adaptive models, highlighting their universal applicability in diverse innovation ecosystems. This underscores the strategic importance of expanding adaptive innovation management practices across all industry segments, ensuring greater agility, resilience, and market competitiveness in an era of accelerating technological transformation.

The empirical analysis results demonstrate that adaptive hybrid models, which strategically integrate institutional guidelines with practical, flexible methodologies, enable more efficient innovation process management. This integrated approach allows firms not only to respond proactively to

market and technological dynamics but also to maintain long-term competitiveness, significantly enhancing the likelihood of innovation success. By combining structured governance with iterative, market-driven adaptability, these models provide a resilient framework for organizations navigating complex and rapidly evolving innovation ecosystems.

5. INTEGRATION OF DIGITAL TOOLS AND DATA ANALYTICS AS A FUNDAMENTAL ELEMENT OF NEXT-GENERATION TECHNOLOGY TRANSFER PARADIGMS

Digital technologies, artificial intelligence, and big data analytics have emerged as key drivers in the evolution of innovation management, fundamentally transforming traditional technology transfer approaches. The integration of AI-driven solutions enables organizations to overcome critical barriers in innovation commercialization, including risk management, market uncertainty reduction, and optimal resource allocation. This shift establishes a new paradigm in technology transfer, one that is anchored in real-time data analytics and adaptive decision-making systems. By leveraging advanced computational models, AI facilitates predictive insights, automated knowledge dissemination, and dynamic strategy optimization, ensuring that technology transfer processes become more agile, responsive, and strategically aligned with evolving market and industry conditions [36].

Digital tools-including automated innovation management systems, IoT solutions, virtual collaboration platforms, and intellectual property management systems-offer substantial advantages by enabling companies to more precisely and efficiently manage technology development cycles. These technologies enhance data-driven decision-making, streamline technology transfer processes, and improve cross-functional collaboration, ultimately accelerating innovation commercialization.

However, the integration of digital tools within organizations requires transformational changes not only at the technological level but also at the organizational and cultural levels. Successful implementation demands significant investments in human capital development and knowledge acquisition, ensuring that employees can effectively leverage these tools. Therefore, digital transformation should not be perceived merely as a technological upgrade but as a strategic management challenge, requiring a holistic approach to change leadership, workforce reskilling, and organizational agility to fully realize its potential in next-generation technology transfer paradigms [41].

To assess the practical application of AI and digital tools in innovation management models, this study conducted a qualitative content analysis, reviewing scientific publications, industry reports, and publicly available documents from leading technology firms over the period 2017–2024.

The analysis revealed that AI and digital technologies have not yet produced fully standardized or ready-to-deploy innovation management models. Instead, existing digital solutions are predominantly customized to specific corporate contexts and are not employed as universal substitutes for adaptive hybrid models. Rather, they serve as enhancement mechanisms, augmenting the efficiency, agility, and decision-making capabilities of existing innovation frameworks. This finding underscores that while AI-driven solutions play a transformative role, their integration remains highly contextual, necessitating strategic alignment with sector-specific and organizational innovation needs [42].

The analysis revealed that companies often face technical and cultural barriers in AI implementation, along with challenges related to data quality and accessibility, which limit the potential impact of digital tools on innovation management. These constraints highlight the need for robust data governance strategies, workforce digital upskilling, and organizational readiness to fully leverage AI-driven capabilities [43]. However, the content analysis also identified significant opportunities associated with digital technology integration, including enhanced predictive accuracy, faster market responsiveness, and substantially improved risk management efficiency. These findings suggest that while technical and organizational hurdles persist, the strategic deployment of AI and digital tools can create a transformative impact on innovation commercialization and competitive positioning.

In the biotechnology sector, the application of AI in molecular modelling and clinical research has radically reduced research and development (R&D) timelines, accelerating the pace of innovation. A notable example is DeepMind's AlphaFold system, which enables highly accurate protein structure prediction, significantly shortening drug development cycles and optimizing resource utilization. By enhancing computational efficiency and reducing experimental dependencies, AI-driven approaches are transforming biopharmaceutical innovation, facilitating faster, more cost-effective breakthroughs in drug discovery and personalized

medicine [44].

In the artificial intelligence and IT sectors, platforms such as Google Cloud AI and Microsoft Azure AI enable real-time data analytics, allowing companies to continuously adapt their product offerings in response to dynamic market shifts. These AI-driven solutions enhance predictive modeling, demand forecasting, and automated decision-making, empowering firms to optimize business strategies, streamline operations, and maintain a competitive edge in rapidly evolving digital ecosystems. The integration of cloud-based AI services fosters agility, scalability, and data-driven innovation, reinforcing their critical role in next-generation technology commercialization and adaptive business models [45].

In traditional manufacturing industries, such as food processing, platforms like Siemens MindSphere [46] and IBM Food Trust [47] provide companies with advanced capabilities for real-time quality control and production process optimization. These industrial IoT (IIoT) and blockchain-based solutions enable enhanced traceability, predictive maintenance, and supply chain transparency, ensuring higher efficiency, reduced waste, and compliance with stringent regulatory standards. By leveraging real-time data analytics and AI-driven automation, these technologies significantly improve operational resilience and adaptability, reinforcing their role in modernizing traditional production systems.

The results of the qualitative content analysis confirm that the integration of digital technologies and AI into technology transfer models has not yet reached full theoretical and practical maturity to completely replace traditional frameworks. However, these technologies are already driving paradigmatic shifts in innovation management processes, significantly enhancing efficiency and competitiveness across industries. This transformation presents a scientifically intriguing and promising research direction for the development of next-generation innovation management models. As digital tools continue to evolve, they may enable the full realization of digital transformation in technology transfer, ultimately laying the foundation for universal, AI-driven innovation management frameworks that could redefine industry best practices in the near future.

CONCLUSIONS AND RECOMMENDATIONS

The study provides an updated perspective on the enhancement of technology transfer models, emphasizing the necessity of adaptive hybrid frameworks. These models seamlessly integrate the structured approach of traditional methodologies with institutional and conceptual strategies, while also leveraging the flexibility of advanced digital technologies to continuously improve innovation management outcomes. Despite ongoing advancements, innovation commercialization success rates remain a challenge for organizations worldwide.

Empirical findings validate the initial research hypothesis, demonstrating that the integration of traditional, institutional, and digital components significantly enhances the efficiency of innovation commercialization. This reinforces the strategic importance of hybrid models, which enable firms to navigate technological disruptions, optimize risk management, and capitalize on emerging market opportunities in an increasingly volatile business environment.

For policymakers and industry leaders, it is imperative to consider strategic initiatives that foster digital skill development and investments in technology infrastructure, thereby creating favorable conditions for the adoption of adaptive hybrid models in AI-driven technology transfer. These continuously evolving models would empower businesses to effectively manage risk and maximize the potential of technological opportunities in dynamic market conditions.

Future research should focus on empirical validation of adaptive model effectiveness across diverse countries and industries, allowing for an assessment of their universal applicability. Additionally, further investigation is required to evaluate the influence of cultural, economic, and institutional factors on the effectiveness of digital tool and AI integration, thereby developing scientifically grounded recommendations for the broader international dissemination of innovation management models.

EDITORIAL POLICY

The submitting author confirms that the submission of this manuscript has been approved by all coauthors and necessary consents have been obtained from sponsors before submission. All relevant prior work has been cited appropriately.

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